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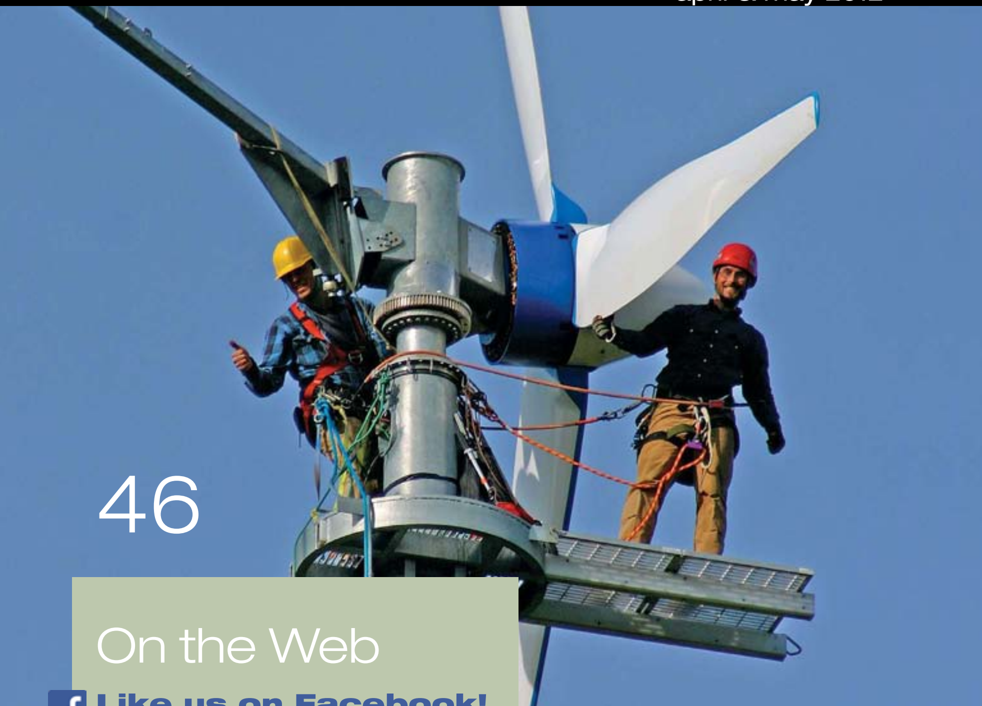

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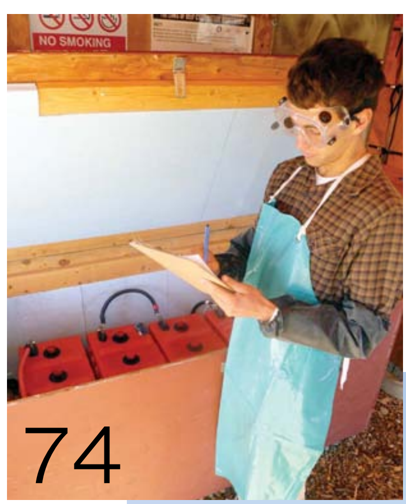
On the Cover

Home Power **CEO Joe Schwartz enjoys the rarified air high above obstructions—where wind generators belong—with an ARE 110 wind turbine.**

Photo: Shawn Schreiner



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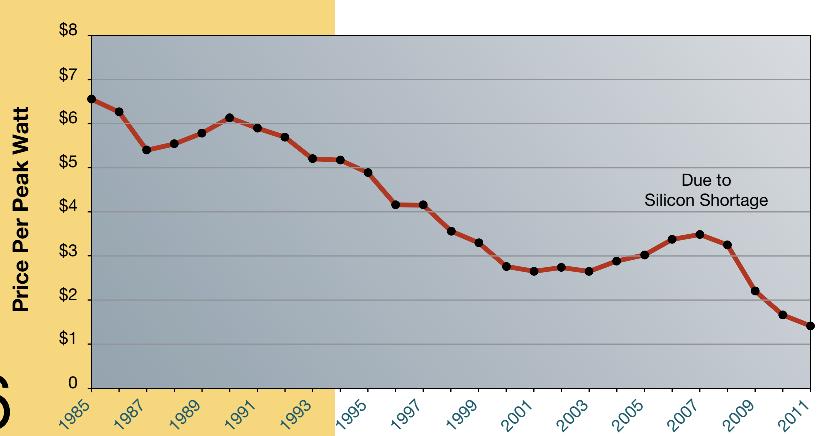

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Getting an Energy Education

Recently, in my family's quest to make our homestead net zero-energy, we installed a 9.7 kW grid-tied PV system on the roof of our newly built passive solar house. Yes, it's a "big" solar array, but since our homestead has two units—a main and guest house—we designed the system to cover *all* of our electrical loads.

We also wanted to make sure we don't squander the solar energy we're harvesting, which can be especially precious during Oregon's cloudy winters. After all, energy saved is energy we don't have to produce or pay for. A TED5000 energy monitoring system helps us keep an eye on our system's generation and our usage. Since we're an *almost* all-electric homestead (we use wood for supplemental heating), getting a handle on our energy use was pretty straightforward with TED. Now we can see when our backup hydronic system is running and make thermostat adjustments accordingly, or be alerted when the guest house is using a lot of energy, for instance, if a space heater is accidentally left on overnight.

The TED meter display, located in our kitchen, gives real-time feedback on our energy usage—and, boy, does your behavior change when the meter starts reporting a $0.60 per hour electricity charge or you watch those kilowatt-hours climb. TED also gives us a daily adjusted projection of what our electricity bill might be at the end of the month.

Before TED, we were scratching our heads at why our past few months' electricity bills had almost doubled. A few current sensors on select circuits later, and we had identified the house's major load—the backup radiant floor system—and also found out that the guest house was using two to three times the electricity that the main house was. We used that information to adjust our energy use accordingly.

Energy monitoring has come a long way. The first tools I used back when I started my energy education more than a decade ago were Kill A Watt and Watts Up? meters. They were handy tools for sure, but only gave a narrow snapshot of my energy use, appliance by appliance. I used them to help decide what to keep (and what to lose) when I moved into an off-grid cabin. Toaster? Passed on to a friend. Boom box? Good to go. In my backwoods cabin, the only ongoing insight into my energy use was the indicator lights on a crude battery monitor. When it dropped to the last two lights, I knew that I'd better turn off the stereo and lights for the night. The sophistication and user-friendliness of household energy-monitoring systems are indications of how far solar energy has come.

Of course, off-grid RE systems force you to live within your means—once the batteries are discharged, it's lights out, literally, or time to fire up the generator. Besides custom or expensive monitoring systems, on-gridders haven't had affordable access to energy consumption feedback—until recently. Having a daily dose of energy education is one way to change how people use electricity in a significant and lasting way. For us, it's been a small investment that has made a *big* difference.

—Claire Anderson, for the *Home Power* crew

Think About It...

It is a capital mistake to theorize before one has data.

—Arthur Conan Doyle, Sr.

contact us

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Low-Priced Chinese PV Modules

Good or Bad for the U.S. PV Industry?

Where you stand on the controversy of Chinese photovoltaic module imports to the United States likely depends on where you sit in the American solar industry. While there is a huge boom going on in the U.S. PV *installation* industry, there is a huge bust going on in the U.S. PV *manufacturing* industry.

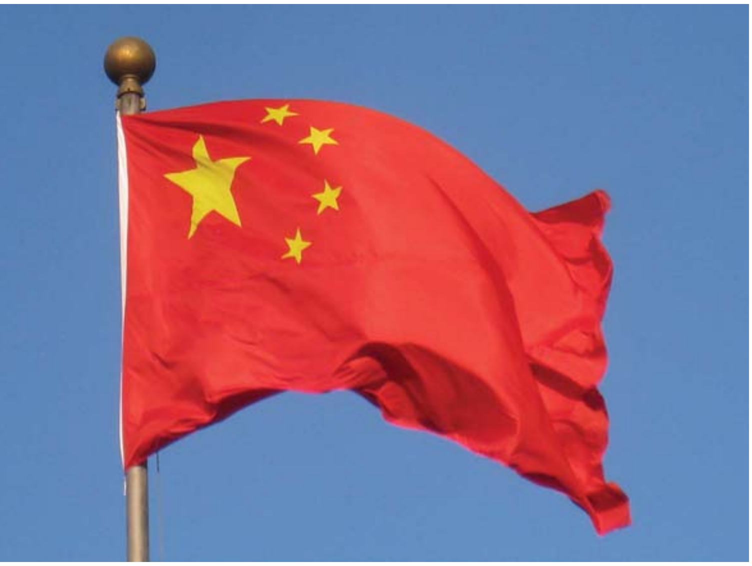
According to the Solar Energy Industries Association (SEIA), a Washington, DC-based trade group, there are more than 100,000 jobs in the U.S. solar industry, a doubling since 2009. SEIA states that the industry grew 69% in 2010, a time when very few American industries were growing. Much of this growth is driven by record-low prices for PV modules, which usually comprise more than half of a PV system's cost. Currently, most of these modules are coming from China.

In August 2011, three American PV manufacturing companies went bankrupt. Two European-based companies shuttered their U.S. module manufacturing facilities. In all, about 20% of U.S. PV manufacturing capacity was lost. While not all bankruptcy problems can be blamed on imports, there is no doubt that it was a significant factor.

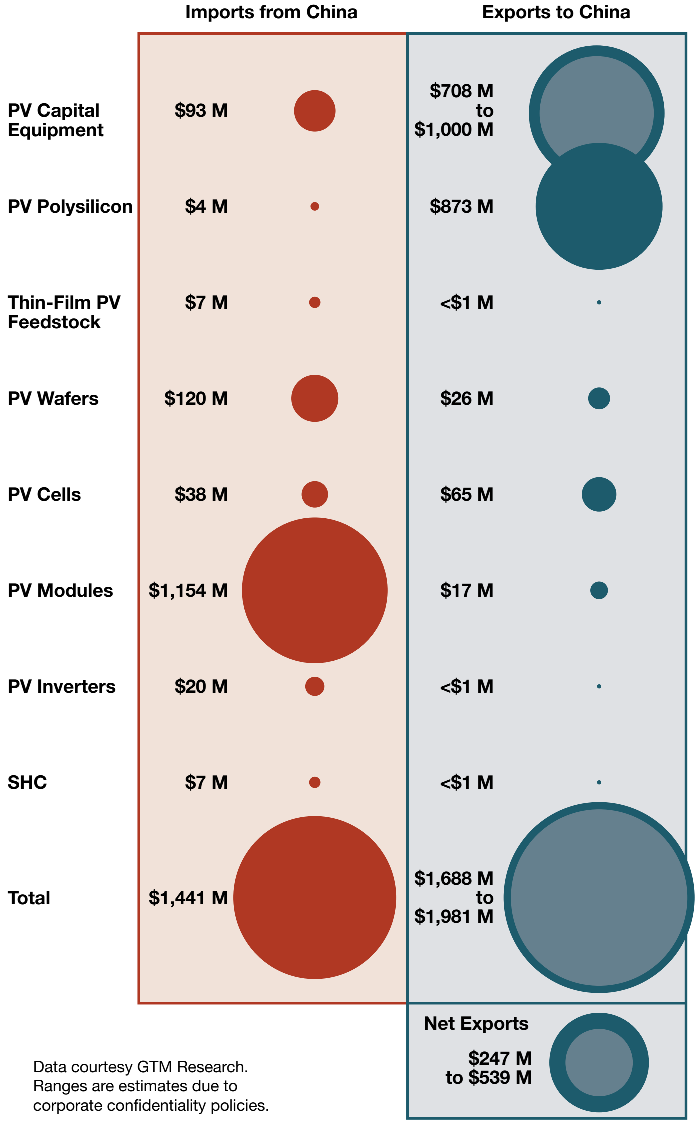
In October 2011, SolarWorld and six other unnamed parties filed a formal complaint against Chinese producers with the U.S. International Trade Commission. In December 2011, the quasi-federal agency unanimously found that Chinese PV imports harmed the U.S. PV manufacturing industry by "dumping"—selling modules below their cost of manufacturing and marketing.

Punitive tariffs of between 50% to 250% could be imposed in 2012. An additional issue, to be decided later, is whether China is subsidizing module export. If so, that could result in additional sanctions of 100% or more.

The filing organization, the Coalition for American Solar Manufacturing (CASM), claims that the Chinese companies and government are violating both international and domestic trade rules—that China, through "its state-controlled financial, utility,



2010 U.S. / China PV Trade



Data courtesy GTM Research. Ranges are estimates due to corporate confidentiality policies.

and other institutions, intermingled with its solar manufacturing industry, has deployed an arsenal of land grants, contract awards, trade barriers, financing breaks, and supply-chain subsidies to advance its pricing and export aggression." CASM also charges the Chinese with "impeding imports" and says that China's PV industry "sidesteps U.S.-level manufacturing standards for labor, quality, and the environment."

Another group, the Coalition for Affordable Solar Energy (CASE), comprised of other solar industry companies such as U.S. module importers and installers, opposes the tariffs on Chinese modules. CASE asserts that "global competition is making affordable solar energy a reality in America and around the world" and "protectionism drives up the price of solar electricity and negatively impacts more than 5,000 American solar companies, mostly small businesses, and more than 100,000 American jobs." It says that "[s]elfish anti-trade actions places [17 gigawatts of] contracts, along with state renewable portfolio standards, at serious risk." CASE maintains that "[in] a solar trade war, everyone loses."

The Chinese government denies the claims of CASM and is pushing back by launching an investigation of programs that they claim set trade barriers against Chinese products. In an ironic twist, it is also accusing the U.S. industry of dumping polysilicon, the basic building block of a PV module, into the Chinese market, thereby forcing its companies out of the business. In 2010, the Chinese bought $873 million of American polysilicon. In comparison, China sold the United States $1.154 billion of PV modules. (The value of U.S. PV modules sold *to* China was $17 million.) In 2010, China produced 33% of the world's polysilicon, followed by the United States (25%), South Korea (16%), and Germany (15%).

...PV module consumers want to buy the cheapest modules on the market, which often means a "Made in China" label.

At the same time that it is considering its own complaint with the Chinese Commerce Ministry, Chinese industry is hedging against U.S. tariffs on their product by making plans to move some of their final production to South Korea, Taiwan, and the United States.

According to SEIA, in 2010, the United States exported $5.6 billion and imported $3.7 billion of PV components and products, for a net PV trade surplus of $1.9 billion. That same year, U.S. PV exports to China were close to $2 billion, while imports were $1.4 billion.

The Chinese government invests (it owns most of its banks) in the front end of industries to put up large factories quickly, which drives down product costs and grabs market share. The U.S. government doesn't own banks and offers tax credits to PV module consumers who want to buy the cheapest modules on the market, which often means a "Made in China" label.

Since January 2010, $40.7 billion has been made available to the Chinese PV industry. Compare that to the $1.4 billion of U.S. loan *guarantees* (the federal government is only on the hook if the company fails—like Solyndra did—but most others have not).

The United States used to make televisions, textiles, and shoes until foreign companies ratcheted up their competition using various forms of state capitalism. (The totalitarian Chinese state capitalism is even more efficient than was democratic Japanese government-industrial cooperation.)

As the editors of *Solar Today* magazine (the journal of the American Solar Energy Society) trenchantly note:

The success of China's front-end investment, designed to achieve critical mass and break even quickly, is making some rethink our national emphasis on end-use incentives. We didn't build the railroads by rebating transport costs to farmers: We built them with front-end financing. Tennessee and Michigan appear to have figured this out, and have laid out incentives to get factories built, as a priority over forcing utilities and ratepayers to subsidize PV installations.

Many critics say the United States doesn't have an "industrial policy" for any industry—let alone the PV industry. The U.S. industrial policy for PV, such as it is, is non-permanent subsidies (tax credits and other incentives that expire and have to be renewed) to end users. The U.S. government tried to directly subsidize emerging new solar technologies, but that may have ended with Solyndra's bankruptcy (see "News" in *HP147*). In this global world of manufacturing, if one country's state-owned banks are providing adequate and inexpensive capital and massive infrastructure development and allowing low or no worker and environmental protection standards, how can the U.S. PV industry compete?

—Andy Kerr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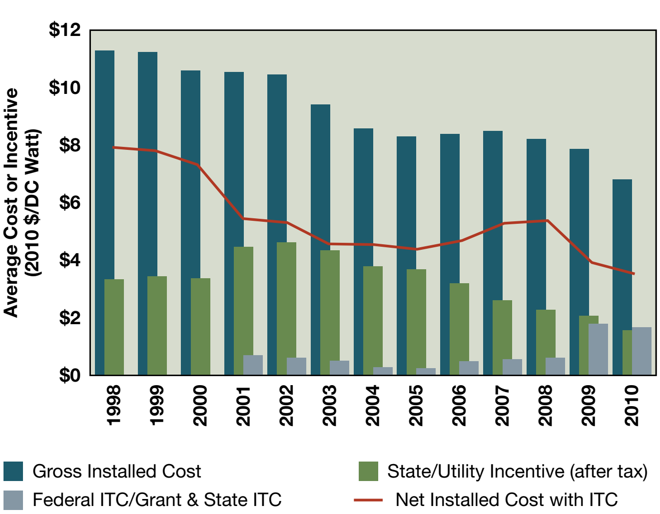
Plummeting PV Costs

The installed cost of non-utility PV systems dropped 17% from 2009 to 2010, according to a report by the Lawrence Berkeley National Laboratory. The capacity-weighted average installed cost was about $6.20 per watt in 2010, down from $10 per watt a decade before. During the first half of 2011, there was an additional 11% decline from 2010. The report examined small (less than 10 kW) to large (more than 1,000 kW) residential and commercial PV systems as well as utility-scale systems. Other major findings:

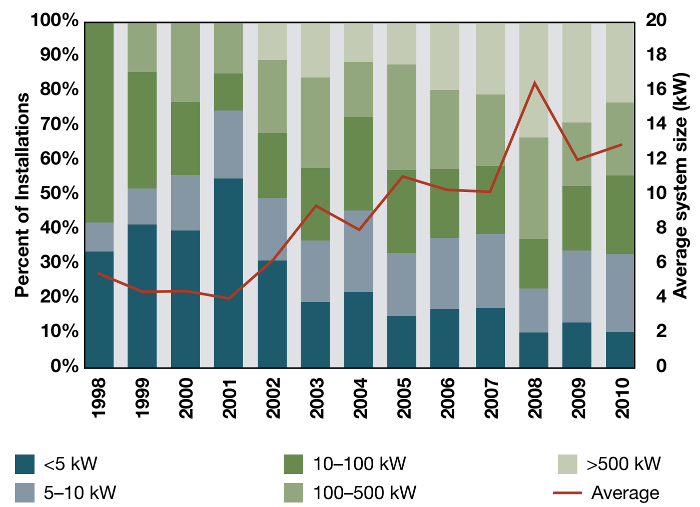
- **Wholesale module prices fell about $1.40 per watt** from 2008 through 2010, and were still falling in 2011. The largest factor for installed cost declines was lower module prices, due to expanding production.
- **Nonmodule and noninverter costs dropped about $0.60 per watt** from 2009 to 2010. All other components constitute the "balance of system," which includes mounting hardware, labor, permits and fees, shipping, overhead, taxes, and installer profit. Inverter costs have stayed fairly level from 2007 through 2010, and the lower costs are attributable to other factors.
- **Systems smaller than 2 kW averaged $9.80 per watt in 2010**, while those greater than 1,000 kW (large commercial systems) averaged $5.20 per watt—47% less. Economies of scale matter, though it's not linear. The cost drops significantly up to a 5 kW system size and then doesn't significantly drop again until a 100 kW system size.

Looking Beyond Net Costs



State/utility subsidies and gross installed costs have been going down, while federal incentives have been increasing.

System Size Distribution



Average PV system sizes are rising.

- **In 2010, overall average installation costs declined** despite reduced average state and utility cash incentives. State and utility incentives continue their general decline. Partially offsetting these decreased subsidies was an increased federal subsidy.
- **Very small systems cost less in new construction** than residential retrofits. Economy of scope matters as well. For small systems, shared transaction and labor costs between the PV installation and other elements of new home construction had cost savings between about $0.70 per watt (2 to 3 kW systems) and $1.40 per watt (1 to 2 kW systems) compared to residential retrofits. However, with larger—but still small (≤10 kW)—systems, there were not significantly reduced costs as system size increased.
- **90% of the projects analyzed were 10 kW or less**, but they represented only 34% of total installed capacity. It takes a large number of rooftop systems to equal the capacity of one utility-scale PV plant.
- **Modules with midrange (around 15%) efficiencies** achieved the lowest installed system costs in 2010. If you have the space, choose modules that are the most cost-efficient ($/W) over those that are the most efficient.
- **U.S. PV installations have grown exponentially**, but PV-generated energy still only contributes about 1% to the U.S. energy mix.

—Andy Kerr

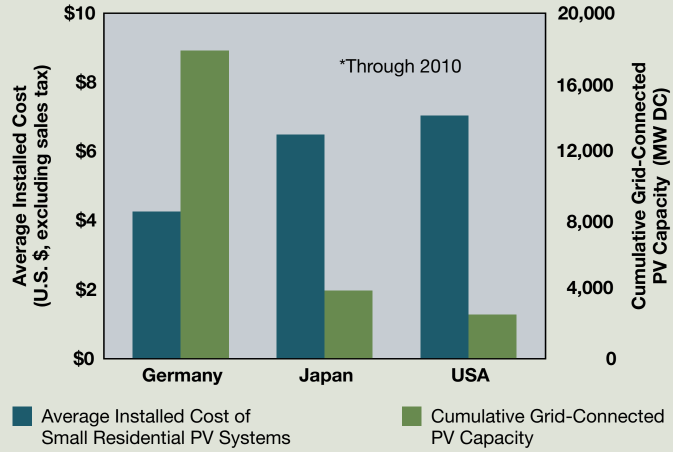
It's Attitude More than Latitude

Berlin, Germany, is further north than Saskatoon, Saskatchewan, Canada. Comparatively, the overcast over Hanover makes Seattle seem sunny. Yet, in 2010, according to the International Energy Agency, Germany installed 7,411 megawatts (MW) of PV capacity, while Japan, at 991 MW, barely surpassed the United States (918 MW). Per person, Germany has 212.5 W of installed capacity, with Japan at 28.3 and the United States at 8.1.

The primary German PV subsidy is the feed-in tariff (FIT), a guaranteed purchase price that the utility must pay for a specified number of years. That certain future income attracts investors today.

The graph (at right), however, which doesn't factor in any FITs, shows that the upfront installed cost in Germany is significantly lower than in the United States or Japan. The data for Germany understates the German cost as it is an average of the 2009 ($4.70/W) and 2010 ($3.70/W) figures.

System Costs Compared



Data courtesy: *Tracking the Sun IV, Lawrence Berkeley National Laboratory.*

Renewable Energy Events

Northwest & Alaska

- **April 21, Douglas County Earth Day & Energy Fair**, Roseburg, OR www.recyclepower.org/earthday.htm
- **April 25–28, Northwest Solar Expo**, Portland, OR www.nwsolarexpo.com
- **May 5, Lacey Alternative Energy Fair**, Lacey, WA http://bit.ly/LaceyFair
- **July 28, Shoreline SolarFest**, Shoreline, WA www.shorelinesolar.org
- **July 27–29, SolWest Renewable Energy Fair**, John Day, OR www.solwest.org
- **August 4, Alaska Renewable Energy Fair**, Anchorage, AK www.realaska.org

Courtesy Clinton Sander (2)

West

- **April 26, Milford Utah Renewable Energy Fair**, Milford, UT www.sutrec.org
- **September 1–2, Crestone Energy Fair**, Crestone, CO www.crestoneenergyfair.crestonecolorado.com
- **September 15–16, Sustainable Living Fair**, Fort Collins, CO www.sustainablelivingfair.org

Northeast

- **March 24, Northeast Kingdom Energy Expo**, Lyndonville, VT www.nvda.net
- **May 11–13, Solar & Wind Expo**, Timonium, MD www.thesolarandwindexpo.com
- **May 19, Living Green & RE Fair**, Salem, MA, www.salem-chamber.org/livinggreenfair34.html
- **July 20–22, SolarFest**, Tinmouth, VT, www.solarfest.org
- **August 17–19, Solar & Wind Expo**, Marlborough, MA www.thesolarandwindexpo.com
- **September 21–23, Pennsylvania Renewable Energy Festival**, Kempton, PA www.paenergyfest.com

Courtesy Clinton Sander

For the Pros

- **March 19–21, PV America**, San Jose, CA, www.pvamericaexpo.com
- **May 13–17, Solar 2012** (World RE Forum), Denver, CO www.nationalsolarconference.org
- **June 11–13, Small Wind Conference,** Stevens Point, WI www.smallwindconference.com
- **July 9–12, Intersolar North America**, San Francisco, CA www.intersolar.us
- **September 10–13, Solar Power International**, Orlando, FL www.solarpowerinternational.com

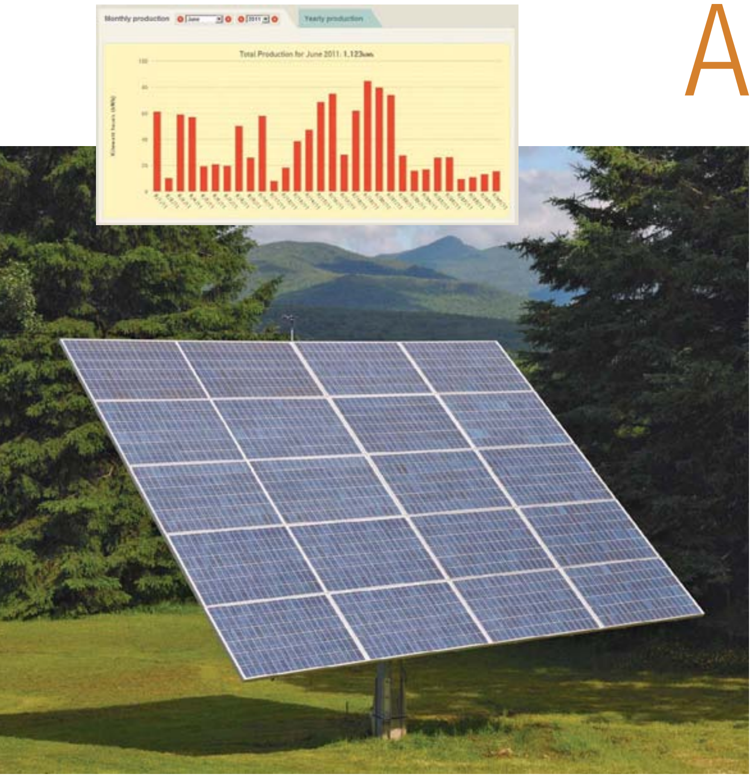
Midwest

- **March 17, RE & Conservation for Homeowners Expo**, Ottumwa, IA www.indianhills.edu
- **June 8–10, Iowa RE Expo**, Cedar Rapids, IA, www.irenew.org
- **June 15–17, The Energy Fair** (aka MREF), Custer, WI www.midwestrenew.org
- **June 22–24, Michigan Energy Fair**, Ludington, MI, www.glrea.org
- **July 20–21, Nebraska Energy Fair**, Lyons, NE, http://nlhrcd.org
- **August 11–12, Illinois RE & Sustainable Lifestyle Fair**, Oregon, IL, www.illinoisrenew.org
- **August 18, Polk County Energy Fair**, St. Croix Falls, WI www.polkcountyenergyfair.com

Courtesy SolWest

Courtesy Clinton Sander

AllSun Dual-Axis PV Tracker



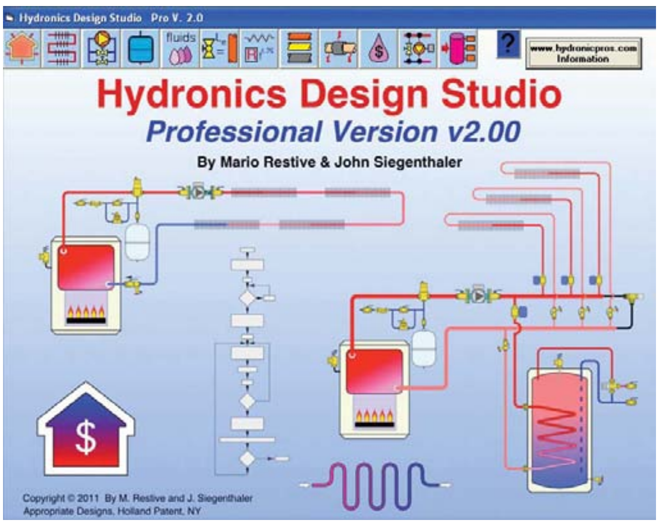
Courtesy AllEarth Renewables (2)

AllEarth Renewables (www.allearthrenewables.com) released its AllSun dual-axis tracker last spring. AllEarth offers complete packaged systems, which include PV modules, an inverter, the tracker, and a remote system monitoring (all shippable on a single pallet). Consumers can choose from 20-module (4,200 W) or 24-module (5,520 watts) model. Each packaged system is covered by a 10-year limited warranty, in addition to the 25-year PV module performance warranty. Note: PV modules can be sourced separately. The AllSun tracker utilizes GPS technology for active tracking, thus it can track the sun even during cloudy weather (so that it is aimed in the correct position for when the sun eventually emerges). The tracker is designed to automatically shed snow and to stow itself during high winds. The remote system monitoring provides users with daily, monthly, and yearly energy (kWh) production values via the AllEarth energy production webpage. The increase in system production for tracking systems (as compared to fixed arrays) can be up to about 45%, but as always, to get the full benefit of a tracking array, dawn to dusk solar access is required.

—Justine Sanchez

Appropriate Designs

Hydronics Design Studio



Courtesy Appropriate Designs

Appropriate Designs (www.hydronicpros.com) has updated its Hydronics Design Studio, which assists in designing and analyzing hydronic heating systems, to version 2.0. Users can choose from several program modules, including a heat-load estimator, pipe sizing, expansion tank sizing, and a heating cost estimator—in a graphical user interface. Also included are modules to calculate fluid properties, equivalent lengths, and hydraulic resistance, and simulators for analyzing series baseboard design, hydronic circuits, injection mixing, and buffer tank selection. This version has a more powerful heat-load estimator; an expanded selection of 440 different circulators; a more comprehensive selection of fuel options, including wood pellets and shell corn; and a new module for equivalent lengths of user-specified materials. Current owners of previous versions can upgrade to the latest version at a discounted price.

—Chuck Marken


Experience the SOLAR Effect!

Barefoot "Solar Engineers"

Since 2004, the Barefoot College—located in the rural village of Tilonia in Rajasthan, India—has brought more than 140 women from 15 African nations as well as Bhutan, Afghanistan, and Bolivia to train as "Barefoot solar engineers," or, more accurately, solar technicians.

Few of the women had ever left their villages or even seen an airplane—much less flown in one. Most did not know how to read or write, and could not speak the local Rajasthan language. Yet, in only six months, the women, both young and old, learned to install, operate, and maintain solar power systems and technologies.

"In six months, how do we change these women? Sign language. You don't choose the written word. You don't choose the spoken word. You use sign language," says Sanjit "Bunker" Roy, who founded the school in 1972.

Bunker was educated at two of India's finest universities, but instead of pursuing a career in medicine and government as his parents had hoped, then-20-year-old Bunker chose to work as a laborer in remote villages. He observed the people and used what he learned to develop a new approach to education for the poor.

More than four decades of trial and error have given way to his unique process that has inspired the creation of 24 other rural colleges in India. The college is exclusively for the rural poor—and managed with collective decision-making and little hierarchy.

The solar technician program is just one of many training sessions offered. The college prepares "Barefoot professionals" with skills in everything from dentistry and midwifery to accounting and masonry. The college began with a group of urban-educated professionals who taught classes, but many would not stay long and returned to the city to make more money. Bunker realized that, if the school were to be sustainable, he needed to train local people to be teachers.

Skills are taught through a system that combines sign language, color codes, and even puppets. "It's the only college where the teacher is the learner, and the learner is the teacher. And it's the only college where we don't give a certificate. You are certified by the community you serve," he says. "You don't need a paper to hang on the wall to show that you are an engineer."

One lesson Bunker learned early on was the importance of women to the sustainability and ultimate success of the college. "Men are restless, men are ambitious, men are compulsively mobile, and they all want a certificate," Bunker says. "Why? Because they want to leave the village and go to a city, looking for a job. So we came up with a great solution: Train grandmothers."

Barefoot's solar program aims "to decentralize and demystify solar technologies" by making them available to remote and non-electrified villages. In an initial meeting, community members are briefed on solar-powered lighting and its benefits. If villagers express the need for solar lighting, then a committee of elders, both men and women, is assembled to manage the program locally and select a few individuals to attend Barefoot College's six-month training program. The village must also agree to build or donate

A Model of Self-Sufficiency

The Barefoot College campus is as impressive as the training being done there, and serves as a shining example of what's possible with rural electrification. Completed in 1989 at a cost of $1.50 per square foot, the 30,000-square-foot campus operates in tandem with the college's original home—a leased, abandoned tuberculosis sanatorium where some classes are still held. Twelve "Barefoot architects" designed and built the 24-building campus over three years.

Designed to be self-sufficient, the new campus runs on various solar technologies. Electricity for computers, lighting, fans, a fridge/freezer, and communications is supplied by a 45-kilowatt PV system. "So long as the sun shines, we'll have no problem with power," Bunker says. All of the food served on campus—roughly 60 meals twice a day—is cooked in parabolic solar cookers fabricated by women trained at the college.

Water is harvested on-site from rooftops and stored in a 100,000-gallon underground tank. Today, the college helps other villages, both in India and abroad, implement similar rainwater-harvesting systems.

Courtesy Barefoot College (2)

a building for storing the components and equipment needed for repairing and maintaining the solar systems.

Barefoot's program requires every member's family to make a small donation every month. This, according to Barefoot's methodology, is so that even the poorest of the poor can feel a sense of ownership.

Upon completion of the training, the technicians can install integrated circuit boards for solar lights and 500 W off-grid solar systems. They can also assemble simple solar lanterns, as well as parabolic solar cookers and solar water heaters.

The true success of the college can be measured best by the people and their accomplishments—like the two illiterate women from Gambia who used their training to install solar lighting systems to serve all the homes in their communities. Then, there are the three women who traveled from Afghanistan with their husbands and returned home to train 27 more women to bring solar electricity to 100 villages. One of the women—a 55-year-old grandmother—"actually went and spoke to an engineering department in Afghanistan and told the head of the department the difference between AC and DC. He didn't know," Bunker says.

—Kelly Davidson

web extra

As a nongovernmental organization, Barefoot College relies largely on donations and grants. Bunker hopes to bring women from other countries to train as Barefoot professionals. To learn more, visit **www.barefootcollege.org.**

Three Solutions for Preventing SHW Overheating

1. Simple Yet Elegant Adjustable Shade

Chuck Marken's thorough article "Overcoming Overheating" in *HP142* inspired me to design a movable cover for a glycol-based solar heating system at a home in the southwest corner of New Mexico. The system was designed for year-round use—in the summer, the near vertical tilt of the collectors helps reduce heat gain, and the shade-cloth curtain provides additional insurance against overheating. It's a simple, straightforward design that took just a few hours to fabricate and attach to the existing collector support structure.

Brackets bolt to the collector mounting frame. The brackets stick out an extra foot at one end to leave room for the curtain fabric to bunch up when fully retracted. Square tubing at the elbows provides needed rigidity. A cable tightened with a turnbuckle runs horizontally between the brackets at both the top and bottom. To prevent droop in the middle, more brackets can be added midway, with slots on top to route the wire. This allows the cloth to pass by the intermediate upper brackets when the upper wire is momentarily lifted out of its slot. The curtain is made from gardener's shade cloth, a dense weave of polypropylene that, with the particular product I chose, blocks up to 95% of the sun's rays. The shade cloth is available with grommets, making curtain-hanging easy.

This fabric is tough stuff, designed to stand up to hot sun and high winds. Order to size at any large garden supply store. Be sure to specify 95% shade cloth taped on all seams, and grommets every 6 inches on all four edges. Use every other hole, so there will be spare grommet holes in place should anything tear over time.

The cloth slides easily along the wire to any position. Secure both ends—I chose the black rubber tie-downs used by truckers to hold down their tarps. These have an S-hook at each end, and are available in many lengths. The custom-cut and -edged fabric cost $200 for an 8- by 40-foot piece. Custom-welded brackets and miscellaneous hardware cost an additional $430.

Seasonal adjustments to cover and uncover some or all panels are easy. It's quite a relief to be able to throttle back excess summer sun in controlled increments whenever the heating fluid gets too hot for comfort. The decision of when and how far to manually move the cover is based on thermometer readings that monitor the glycol loop's temperature. Adjusting the curtains twice a year, with the seasons, does the job here, but your climate and heat-exchanger response times will dictate how often and how many collectors you'll need to cover.

—Joel Chinkes, Photon Harvest Company

Joel Chinkes

2. Automatic Awning

Our solar-heating system in the high desert of Dyer, Nevada, was designed to optimize production during the winter, which results in excess heat production during the summer. Left unchecked, the system would release the pressure-relief valve and overheat the therapy pool and spaces, and potentially degrade the propylene glycol heat-exchange fluid, increasing the acidity and risking pipe and component corrosion. The system did not incorporate a heat-dissipation coil or other method to dump excess heat, and climbing on the roof to cover the collectors was impractical for myself and my wife. Another plan was required.

We had an electrically operated awning on our motor home, and thought the same principle could be used to shade some of the solar collectors. Awnings were fabricated to cover three 4- by 8-foot collectors (about half of the system at that time). The awning is designed as a window shade for a house or a patio cover, and has an electric motor to extend and retract it. During high-wind events (greater than 25 mph), an anemometer automatically signals the controller to close a switch, which retracts the awning.

A Goldline GL30 differential controller with a digital readout panel activates the motor to extend the awning

David Sweetman (2)

whenever the temperature of the heat-transfer fluid exceeds 180°F. The GL30's normally open contacts are in parallel with the manual switch, so either will operate the motor. Although normally closed contacts could be wired to automatically retract the awning when the temperature drops, we have chosen not to use this function. At night, we usually get enough wind that the anemometer control typically retracts the awning. Otherwise, we can manually retract it when needed, using readings from the digital display of the GL30, which monitors the temperature of the heat-transfer fluid into and out of the solar collectors; the therapy pool; the water tank; and the water exiting the water tank's heat exchanger.

The cost of the awnings and controls was $2,381 (in 2002). The nuts and bolts, GL30, and thermocouples cost less than $250. The awnings were installed on the solar collectors' mounting brackets, which are robust enough for the additional weight and wind load. Installation took about 20 person-hours.

The motor failed after about nine years of operation, which is somewhat longer than average, given the awning gets less-than-average usage. The GL30 uses a variable resistor to allow temperature adjustment for extension. Since this system is dual-purpose—for domestic water and therapy pool heating, with separate heat exchangers—some adjustments are required to prevent inadvertent extension of the awning, such as when the system switches from therapy pool heating to domestic water heating.

3. Shutters

After expanding our therapy pool and water heating system by adding four SunEarth EP-40 collectors for winter heating, additional covering was required for the summer. Since the awning is for intermittent use, we needed a covering that could be used all summer—the three months or so we have excess heat.

Shutters were custom-made to cover the four added collectors (www.rollupshutter.com). Since extension and retraction are by an electrical motor, the exposed surface area of the collectors can be controlled. This is important during spring and fall, when partial heating is required.

These shutters worked so well that when we added a solar radiant floor heating system, we used the shutters to cover the evacuated tubes (180 tubes), since we did not need space heating during the summer (or at least rarely do we need the heating). The evacuated tubes are set in three parallel banks of 60 tubes each, and each bank has a separate shutter. We open (and close) the shutters as necessary during the spring and fall to maintain the correct amount of heat energy in the storage tank (and the temperature in the rooms). Just like the awning system, a Goldline TD6 monitors the temperature of the heat-transfer fluid into and out of the solar collectors; the storage tank (high point and low point); and the floor heating loop inlet.

As with the awning, the shutters are mounted to the top of the collectors' support structure. The collectors are set at an angle of about 60° to maximize energy collection during the winter (we are at 38° latitude). The shutters are normally vertically mounted (e.g., for window or storm door protection), but operate quite easily at this angle. The shutters are insulated and are very effective in shielding and protecting the collectors.

The single shutter to cover the EP-40 collectors cost about $3,350 (in 2005), not including shipping. Installation took about 15 person-hours. The three shutters to cover the added evacuated-tube collectors cost about $5,050 (in 2007), not including shipping.

For applications such as space heating, when solar collectors will not be in service for several months, I think shutters are more efficient and effective than using a separate heat exchanger to dissipate excess heat (as I had used in another space-heating application). Shutters initially cost more than a separate heat exchanger, but the operating cost is much lower, while the effectiveness and reliability are much higher. Awnings and shutters cost the same, but I think shutters are easier to install, and more reliable and effective. One can use a differential temperature controller with electrically operated shutters, but monitoring and manually operating the switch is generally adequate.

—David Sweetman

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Equalizing Batteries

Periodic battery equalization is necessary for the long-term health of your battery bank. This controlled overcharging (increasing voltage) of flooded batteries forces charge through all the cells—even the weakest ones that require more charging to fill. It also helps remove some hardened sulfates from the plates, and remixes the electrolyte, preventing stratification.

Only flooded batteries, not sealed batteries, should be equalized, and at a frequency of about every two to six months. But all systems are different, and knowing when to equalize can save generator run time and extend battery life. Your batteries probably need more frequent equalization if they don't reach 100% full weekly, have unequal cells (voltage or specific gravity), or have reduced capacity.

Since this is a boost that charges beyond normal voltage, unless you have a much larger-than-usual PV array, it requires the grid or a generator. The equalization begins once the batteries have reached their normal full state, and the duration depends on the state of the batteries, their charging source, and available charging current. Each battery manufacturer specifies a recommended equalization voltage. Typically, after equalization voltage has been reached, a maintenance equalization takes between two and three hours.

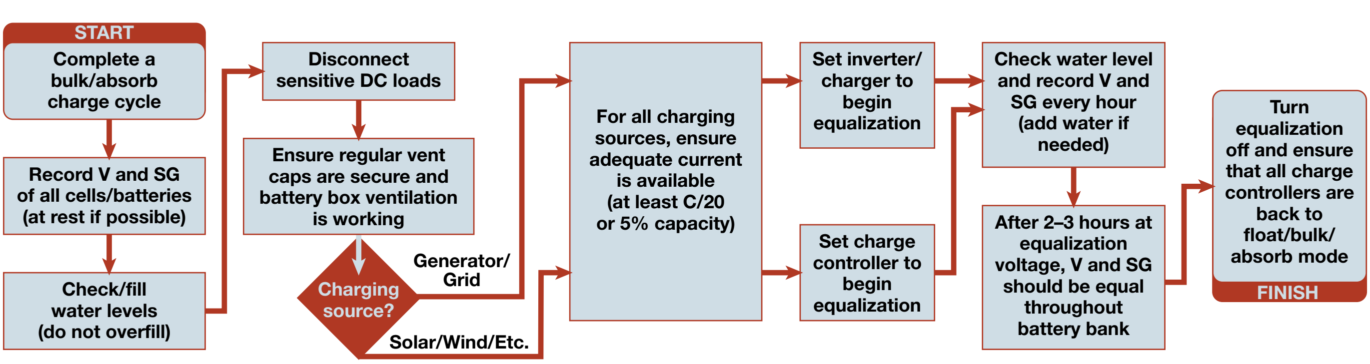
When performing an equalization, any sensitive DC loads should be disconnected. An equalization voltage is too high for some appliances or electronics, and could cause permanent damage.

Electrolyte levels should be checked *before* the equalization, and cells topped off with water if low. Adding water before an equalization is best, since the electrolyte will be thoroughly mixed. But it will be bubbling vigorously and actually expands in volume as the state of charge (SOC) rises, so be careful not to overfill. There should be enough electrolyte in the cell so that the plates will not get exposed even with some water loss during equalization, but not so much that acid will splash out of the vent caps while bubbling. Be sure all vent caps are securely in place before starting the equalization. If your batteries have Hydrocaps, replace them with the normal vent caps during equalization to avoid overheating the recombining catalyst.

There will be significant gassing during the equalization, so be sure the venting is functioning properly and your battery box is closed. If you have a vent fan, double check that it turns on, or if there is an exterior door or window in your battery room, open that, too.

Sulfation is crystallization of sulphur on battery plates, which reduces the contact area between the lead and the electrolyte. If you suspect sulfation problems, you may need to perform a corrective equalization, which takes longer than a maintenance equalization. Signs of sulfation include reduced battery capacity; difficulty reaching bulk voltage; and reduced current availability, making it difficult to power high-surge loads. During a corrective equalization, monitor the water level, temperature, and specific gravity of the cells, and adjust the charging current accordingly. If the batteries get too hot (approx. 120°F; check manufacturer's specs for your batteries), lower the charging current enough to allow the batteries to cool and stay below the high temperature mark. Since this corrective charge can take a long time (five to 10 hours is not uncommon), you may need to add water partway through the process even if the cells were full at the beginning. Before starting, measure the SG of all the cells, and choose a pilot cell, the one with the lowest specific gravity, so you don't have to open every cell throughout this process. Every half hour or so, measure and record the SG of the pilot cell. When it reaches 100% SOC, check the other cells. When they are all at 100% SOC, and stay there for a couple of hours, the corrective equalization is finished.

—Lena Wilensky



Going On the Grid

I've appreciated your advice and support for 23 years, while I've lived off the grid. I started with a used 500 W wind generator, four 33-watt solar-electric modules, four batteries, and a Trace 2012 inverter. Over the years, I turned to *Home Power* every time I wanted to upgrade. Today, two families live on our 48 V, 24-battery bank; the wind generator is a 1 kW Whisper; and there are eight modules and a 5 kW inverter. This month, we are tying into the grid, with a feed-in tariff (FIT) agreement with NIPSCO, the local utility. The gathered and shared wisdom from *Home Power* still guides us.

The ways of the utility company are not easy for us to understand or predict, so you may wonder why we decided to connect to the grid. Our primary reason is to stop maintaining a battery bank. The primary obstacle has been connection cost.

The connection cost 23 years ago would have been about $5,000 for our 1,000-foot lane; that was part of the incentive that led us to try an off-grid renewable energy system then. Over the years, that cost increased; two years ago, we were quoted $10,000 to $12,000. Last year, a NIPSCO engineer told us that there was a ratepayer case in the works that "could work to your benefit." Sure enough, a month later, she said that the new rule meant that they would now hook us up—*for free.*

Courtesy Rich Meyer (2)

Until last September, everyone getting on the solar bandwagon around here was doing a careful calculation, and sizing production to meet 95% of their annual needs. The only option for distributed generation was net metering. A net-metering agreement meant that customers were only charged for the shortfall between what they used and what they generated, but there was no payback for "overproducing" or becoming a positive producer. If you did that, you were giving your surplus RE-generated electricity to the grid as a gift.

Now we have the option (and we're taking it) of becoming a net producer, under a FIT agreement. With this, we simply get two meters—"buy" and "sell"—but no connection on our side, and no kWh comparison is done. We buy what we use (currently at $0.10 per kWh) and the utility buys what we produce. The kicker is, the utility is agreeing to buy our solar production for $0.30 per kWh in year one, with 2% increase per year, for 15 years. The only differences from net metering, besides the price per kWh, is that NIPSCO owns our renewable energy credits (RECs), for what those are worth to them or anyone else, and we can produce more than we use and get paid for it. For whatever reason, they will only pay $0.17 per kWh for wind-generated electricity.

While we don't know what will happen to the cost of grid electricity 12 years from now, even if it rises gradually rather than hugely and suddenly, we'll still do OK. So we just bought 42 solar-electric modules with microinverters, and I'm building racks to put them on the barn roof. The system should pay for itself in seven years. Even in cloudy northern Indiana, at the tip of the lake-effect snowbelt, solar electricity can pay.

I've never been ideologically committed to the independence of stand-alone generation, so utility grid, here we come. I'm glad that NIPSCO wants some green electricity and is willing to pay a premium for it. I'm curious how the cogeneration options we've had here compare with what people in other states are finding. I'll be glad to get rid of the batteries, though sorry to lose the reliability of my off-grid system. (Well, as long as we have 16 good batteries left, I'll keep the wind generator and put in a transfer switch for backup during utility outages.)

Over the years, I've referred lots of RE seekers to *Home Power*. If you call me for advice on what works and whether to get into RE, my first instruction is to subscribe to *Home Power.* Last night, someone called from Ohio wanting advice on whether to put in a wind generator. Interest keeps growing. Keep it up!

Rich Meyer • Millersburg, Indiana

PV After 30 Years

I just replaced six solar-electric modules that have been in continuous use since 1980, and another nine that went up in 1985. They were rated 35 W each, but, of course, even when new they only put out 35 W (wired directly to batteries) when hit by full sun while totally cold.

At the end, the whole array was averaging about half that rated power, but two of the modules had weak cells that cut their output almost to zero under most conditions, so the remaining modules averaged closer to 60% of rated power.

There was no apparent physical damage or difference in the weak cells. I only diagnosed them by measuring individual cell voltages under load, using needle probes pressed through the plastic backing behind the module. All of the six original 1980 modules failed at one particular soldered junction where there was only one metal strip connected to the back of each cell in the array, instead of the typical redundant pair. I learned how to strip off the back plastic and solder the connecting strip back to the backside of that cell. I covered the surgery with a layer of silicone. The photo shows the worst of the older modules.

Six of the newer modules still look and act just like new, after 26 years in the sun.

Loren Amelang • via e-mail

Courtesy Loren Amelang

Base-Load Solution Brainstorming

It seems that regarding energy and environmental issues, large-scale energy providers are always touting the status quo in pushing coal and nuclear power as absolutely essential for providing base load energy. This seems at times to be an entrenched thinking pattern that provides an obstacle to cleaner and greener energy use. Here are some other possibilities of how to move forward and respond to the base load discussion.

Generation:

- Interconnected grid-tied offshore wind systems that provide electricity over long distances
- Large desert thermal-power generating systems with storage of heat in liquid

Delivery:

- Improved and responsive grid
- Super conduction

Storage:

- Hydrogen fuel cells
- Pumped hydro storage

Personal responsibility:

- Rooftop solar thermal

- Community solar- and wind-electric systems
- Home solar- and wind-electric
- Use less
- Energy efficiency—personal and industrial
- Birth control

I hope this is just a small start of a discussion. Please help by sharing your ideas and insights.

Dave Berger • Klickitat County, Washington

Remembering Elliott Bayly

Elliott Bayly was once described to me as having “wind-powered hair and electric eyes.” Those who knew him understand how that phrase succinctly captures his physical appearance, but it does nothing to describe the indomitable spirit embodied within.

A wind-energy entrepreneur, Elliott’s love for the technology and the business kept him moving forward long after others would have given up. The Whirlwind, Whisper, and Ventera product lines all demonstrate design aspects that were exclusively Elliott’s purview; his goal was to produce the most cost-effective wind turbine in the world, and he made great strides toward doing so during his long, eventful career.

One of my fondest memories of Elliott stems from his drive to improve the state of the art of small wind turbines. One sunny fall morning, Elliott and I set out on an adventure. The goal? Truck-testing a new wind turbine design! After tilting up the test stand in the back of the truck, checking for other vehicles and obstructions, and making a few successful trials, we decided it was time for a long data collection run. Both of us were so focused on the performance of the machine in back that we failed to notice the tree limb in front—right up until the time that it smashed into the testing rig, sending broken blade parts raining down upon the cab of the truck. Elliott’s only lamentation was that our day of development and fun was cut short, much like the blades of our test machine!

Elliott Bayly will be fondly remembered by the small-wind industry, and his legacy of success will stand long after his passing. Quick to laugh, warm, witty, and with a genuine sense of empathy, Elliott was one of a kind. Rest in peace, my friend.

—Steve Wilke

Courtesy Mick Sagrillo

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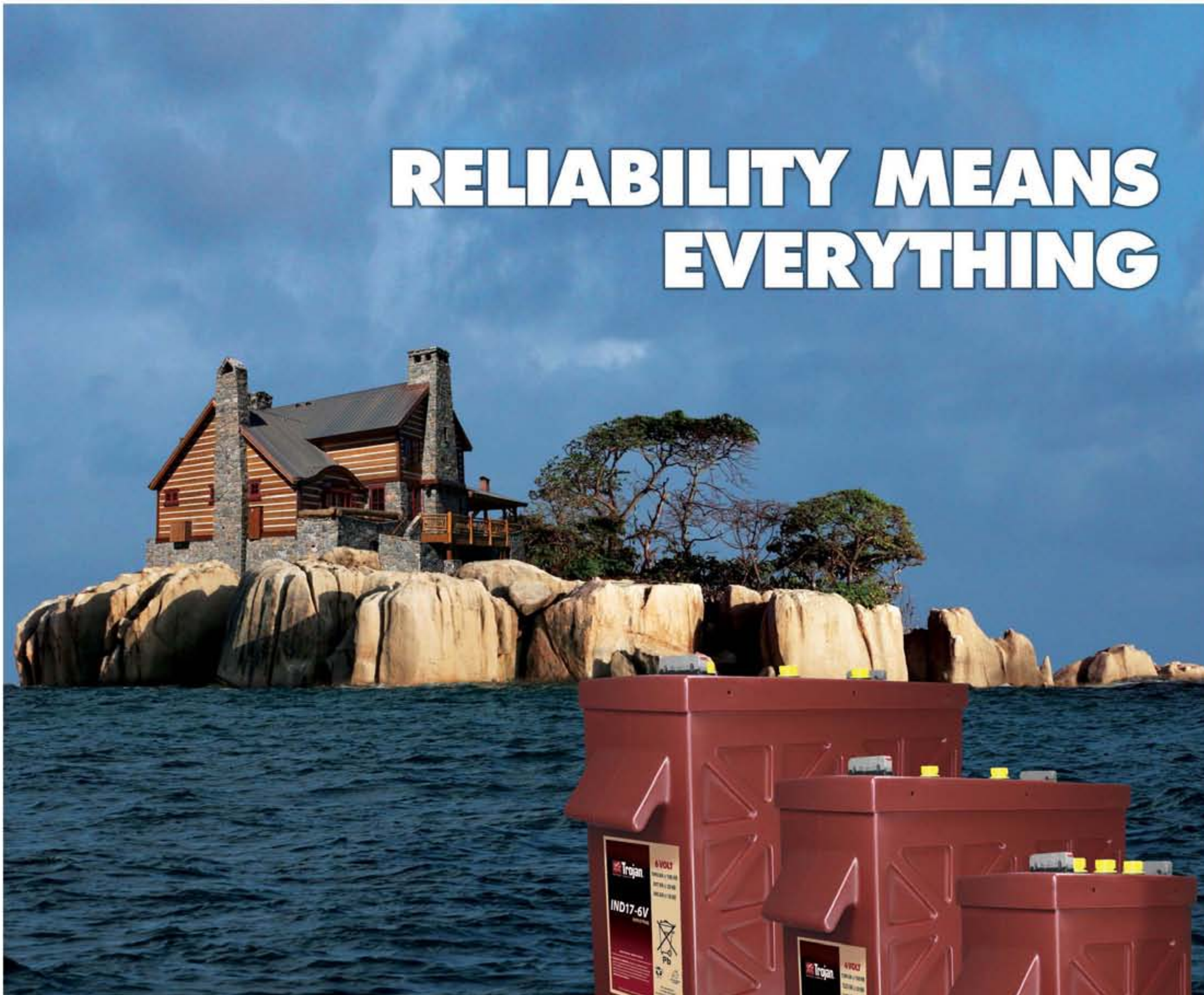

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Conflicting Charge Controllers

I have a wind-PV hybrid system with an 1,800 Ah battery bank at 24 V. The wind generator is a Raum 1,500 W, 24 V battery-charging turbine. I have a 1,300 W solar-electric array with an OutBack MX80 charge controller.

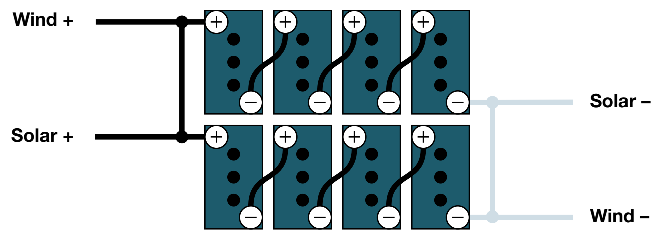
The problem is that the wind generator is sensing a higher battery voltage because of the solar-electric system, so it is not producing its full energy potential. If I switch off the PV system, I get the full energy from my wind generator. Is there a better way to maximize charging?

Charles Huot • via e-mail

All off-grid systems will “waste” energy whenever the batteries are full and you don’t have a use for the electricity. Not being able to use all of the energy potential is a normal drawback of a stand-alone system. PV charge controllers will turn off a PV array when the batteries hit the controller’s high voltage setting. Diversion wind controllers will send energy from the battery bank to a dump load when the batteries hit that controller’s high voltage setting.

Conflicts between PV and wind controllers tied to a single battery bank can lead to the situation you describe, when one energy source and its controller dominates the other. This especially can happen with wind, since large gusts can cause voltage spikes that push the wind controller into diversion mode and the PV controller into regulating mode.

What can you do? If your battery bank is in a series-parallel configuration, one option that sometimes helps is to connect the charging sources to opposite corners of the bank—each controller is connected to different battery terminals. This tends to buffer the high-voltage spikes from the wind turbine in gusty winds, which helps prevent the PV controller from reacting as often to quick voltage rises. This means running the controller wiring all the way to



Two separate charging sources for one battery bank.

the battery bank. If your controllers are connected to the main DC load distribution center and pass through a single battery monitor shunt, this may not be a good option for you.

If the Raum controller’s battery-charging settings are adjustable, another option is to raise the bulk/absorption voltage a bit higher than the MX80’s voltage if you want the wind to lead, or vice versa if you want the PV to lead. On my own off-grid system, I adjust the controller settings seasonally, letting the PV lead in the summer and the wind turbine lead in the winter, when winds are higher.

Ultimately, you want to get the most out of both resources, keeping your batteries full. If you’re a savvy user, you will find ways to use your surplus, like cutting your firewood with an electric chain saw or doing all of your laundry on those sunny, windy days. My wife purchased an electric convection oven, which she uses on sunny, windy days when we have surplus energy. We feel so decadent cooking with electricity in our off-grid home!

Roy Butler, Four Winds Renewable Energy • Arkport, New York

Solar DHW & Heating

I intend to install a solar water heater in a new home that’s being built in southern Maine. I am looking for cost-effective ways to deal with energy costs and the opportunity to offset them with on-site renewable generation. We have reasonably short summers—temperatures rarely hit 100°F—and fairly long and cold winters.

How practical (and affordable) is it to have a single system for both water and space heating (a hydronic baseboard system, perhaps)? Will this system cause problems by producing excess hot water when space heating is not being used?

The house, which will be roughly 2,500 square feet with a small second story, has a fairly open floor plan with a central wood heater that will provide most of the space heating.

John Barbarino • via e-mail

The local winter solar resource and a home’s heat-delivery system are important considerations for evaluating a supplemental solar space heating system’s feasibility. According to NREL’s Redbook weather data, the closest recording stations to southern Maine are Portland, Maine, and Concord, New Hampshire. Portland has a slightly better winter resource, although both locations have an average daily insolation of 4.6 peak sun-hours (kWh/m^2) for collectors facing south and mounted at a latitude tilt angle. A tilt angle of latitude plus 15 degrees favors winter production and the Redbook gives an average resource of 4.2 daily peak sun-hours for the eight months in Portland that require space heating.

When compared to a year-round solar water-heating system, the extra equipment needed for space heating will be used about two-thirds of the time. The components of the space-heating system will have a longer return on investment because of the diminished resource and the shorter period of time the equipment is used each year. In your area, after factoring in the 10% reduced winter resource with the time the equipment is used, the economics of a solar space-heating supplement is marginal. This might be acceptable depending on the heat-delivery method and the cost of the integrating the additional equipment into the existing heating system.

Lower-temperature heat-delivery systems favor solar heating, since collectors operate more efficiently at lower operating temperatures. The collectors lose less heat to the outdoors and consequently produce more usable energy operating at lower temperatures. For this reason, radiant floor systems operating at 100°F to 140°F are excellent delivery systems for solar heat. Baseboard heating systems are typically designed with high-temperature heat delivery because of the cost of the elements—fewer lineal feet of baseboard element are required if higher-temperature water is used. Most baseboard systems are designed to heat the designated space during times of near-record-low outdoor temperatures with a 170°F boiler

NREL Redbook kWh/m²/Day for Portland, Maine

Tilt	Data Type	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
0°	Average	1.9	2.8	3.8	4.7	5.6	6.1	6.0	5.4	4.2	2.9	1.8	1.5	3.9
	Minimum	1.7	2.2	3.1	4.1	4.6	5.2	5.4	4.8	3.9	2.5	1.4	1.2	3.7
	Maximum	2.2	3.3	4.5	5.4	6.6	7.2	6.7	5.9	4.8	3.5	2.0	1.8	4.2
Latitude - 15°	Average	3.1	4.1	4.8	5.2	5.7	6.0	6.0	5.8	5.1	4.0	2.8	2.6	4.6
	Minimum	2.6	3.1	3.7	4.4	4.7	5.0	5.3	5.1	4.5	3.2	1.9	1.9	4.4
	Maximum	3.8	5.1	5.7	6.1	6.7	7.1	6.7	6.4	5.9	5.0	3.3	3.3	5.0
Latitude	Average	3.6	4.5	5.0	5.1	5.3	5.5	5.6	5.5	5.1	4.3	3.1	3.0	4.6
	Minimum	2.9	3.3	3.8	4.3	4.4	4.6	5.0	4.9	4.4	3.4	2.0	2.1	4.4
	Maximum	4.4	5.7	6.0	6.0	6.3	6.5	6.2	6.2	6.0	5.4	3.8	3.8	5.0
Latitude + 15°	Average	3.9	4.7	5.0	4.7	4.7	4.7	4.9	5.0	4.9	4.3	3.2	3.2	4.4
	Minimum	3.1	3.4	3.7	3.9	3.9	4.0	4.4	4.4	4.2	3.4	2.1	2.3	4.2
	Maximum	4.8	6.0	6.0	5.6	5.5	5.6	5.4	5.6	5.8	5.4	4.0	4.2	4.8
90°	Average	3.8	4.4	4.1	3.2	2.8	2.7	2.8	3.2	3.6	3.6	2.9	3.1	3.4
	Minimum	3.0	3.0	2.9	2.7	2.4	2.3	2.6	2.8	3.1	2.8	1.8	2.1	3.1
	Maximum	4.7	5.6	5.2	4.0	3.2	3.0	3.0	3.6	4.3	4.6	3.6	4.2	3.7

City:	Portland
State:	Maine
WBAN No:	14,764
Lat. (N):	44
Long. (W):	70
Elev. (m):	19
Pres. (mb):	1,013
Stn. Type:	Secondary

Source: Solar Radiation for Flat-Plate Collectors Facing South at a Fixed-Tilt, % Uncertainty = 11 http://1.usa.gov/NREL_Redbook

temperature. Lower delivery temperatures with the same amount of baseboard heating can result in a cold home on winter nights.

In the winter, flat-plate solar collectors can't *efficiently* produce 170°F water in southern Maine. Evacuated-tube collectors can do a little better job at producing higher temperatures, depending on the snow load. Evacuated tubes have a superior vacuum insulation that results in more energy produced, even at low winter temperatures. However, this advantage can be compromised because the tubes have limited ability to shed snow.

It is possible to integrate a supplemental solar heating system that is a separate delivery system using the existing baseboard elements. Either a boiler or the stored solar-heated water provides heat to the baseboards. A motorized three-port valve can automate the operation. This would be preferable to any design for integration that uses the solar energy to preheat the boiler return water because of the high temperature required. The stored solar heat will never heat the home on the coldest nights, but can contribute substantially to displacing the conventional boiler fuel, depending on the system size.

Your concern for excess summer production is valid. There are a few solutions in an article in *HP142*—system designs, load diversions, and higher collector tilt angles.

Chuck Marken • *Home Power* solar thermal editor

Since you're in the planning stages of home construction, you're also at the ideal time to integrate passive solar systems. I urge you to put some time and energy into this before you start planning any active solar systems.

Since you're already considering SHW systems, perhaps you've already made sure that you have ample south-facing roof space. If your solar access is good, consider placing most of your windows on the south side and minimize the number of windows or doors on the north, west, and east sides. Select high-performance units that have the lowest U-values you can find. For the south glazing, you'll want windows with a *high* solar heat gain coefficient. In this climate, you may want to specify triple-pane units.

You'll also need to incorporate thermal mass (usually in the floors) and make sure that the foundation perimeter and floor are well-insulated. Using high levels of insulation in the ceiling and walls will also help you reduce the home's supplemental heating requirements. An added benefit of using passive solar design is all the natural light that will flood your house, reducing or even eliminating the need to use artificial lighting during the day.

While I'm beating the passive/efficiency drum, I'd also urge you to consider how much space you really *need*. A 2,500-square-foot home may be considered an "average" size today in the United States, but in 1970, the average-size home was 1,400 square feet. Our family of three lives very comfortably in a new 1,472-square-foot passive solar home. Not only did we save money and resources by building "smaller," but the savings continue year after year, as a smaller, well-built, insulated space means less energy is needed for heating and cooling.

Claire Anderson • *Home Power* managing editor

RE Financing

I recently read "How to Finance Your Renewable Energy Home" in *HP103.* I live in Plattsburgh, New York, and my wife and I are interested in purchasing an energy-efficient off-grid home.

We have a piece of property we are interested in, but with the current economy and few or no off-grid home sales in our area, I am not sure where to find financing. Do you know of any lenders or specialists that may assist us in our area?

Scott Campany • via e-mail

In general, financial institutions do not understand renewable energy (RE) systems, much less off-grid RE systems. It will likely fall to you and your RE installer to educate local institutions on how a code-compliant RE system works. They will also be concerned about the resale value of the home. If anything, the RE system adds value to the home. In my part of New York, off-grid homes never stay on the market long and usually sell at or above the asking price.

The key is to find a loan officer willing to meet with you and, hopefully, keep an open mind. Then stress safety and reliability. You also need to emphasize that the home wiring and appliances will be what they consider "normal." Also be sure to mention that the systems will pass inspection and that you will be able to obtain homeowner's insurance.

But if you cannot get through to your loan officer about RE systems, he or she may be able to understand better the use of an engine generator—they are much more common and potentially acceptable. This doesn't mean you cannot have RE too; the generator is just a more "normal" electrical source that a loan officer might understand.

The challenge is to find an appraiser who can calculate the value of the RE system, which includes the system's installed cost and the value of the energy produced over the system's lifetime. In some cases, off-gridders have to pay a larger down payment or agree to a higher interest rate to secure financing. As with any loan, shop around for the best deal. Enlist the help of a local RE dealer who has had prior experience with financing and installing off-grid RE systems. They may have a good working relationship with a financial institution. Good luck with your project!

Roy Butler, Four Winds Renewable Energy • Arkport, New York

www.dreamstime.com/FabioBerti

write to:

asktheexperts@homepower.com

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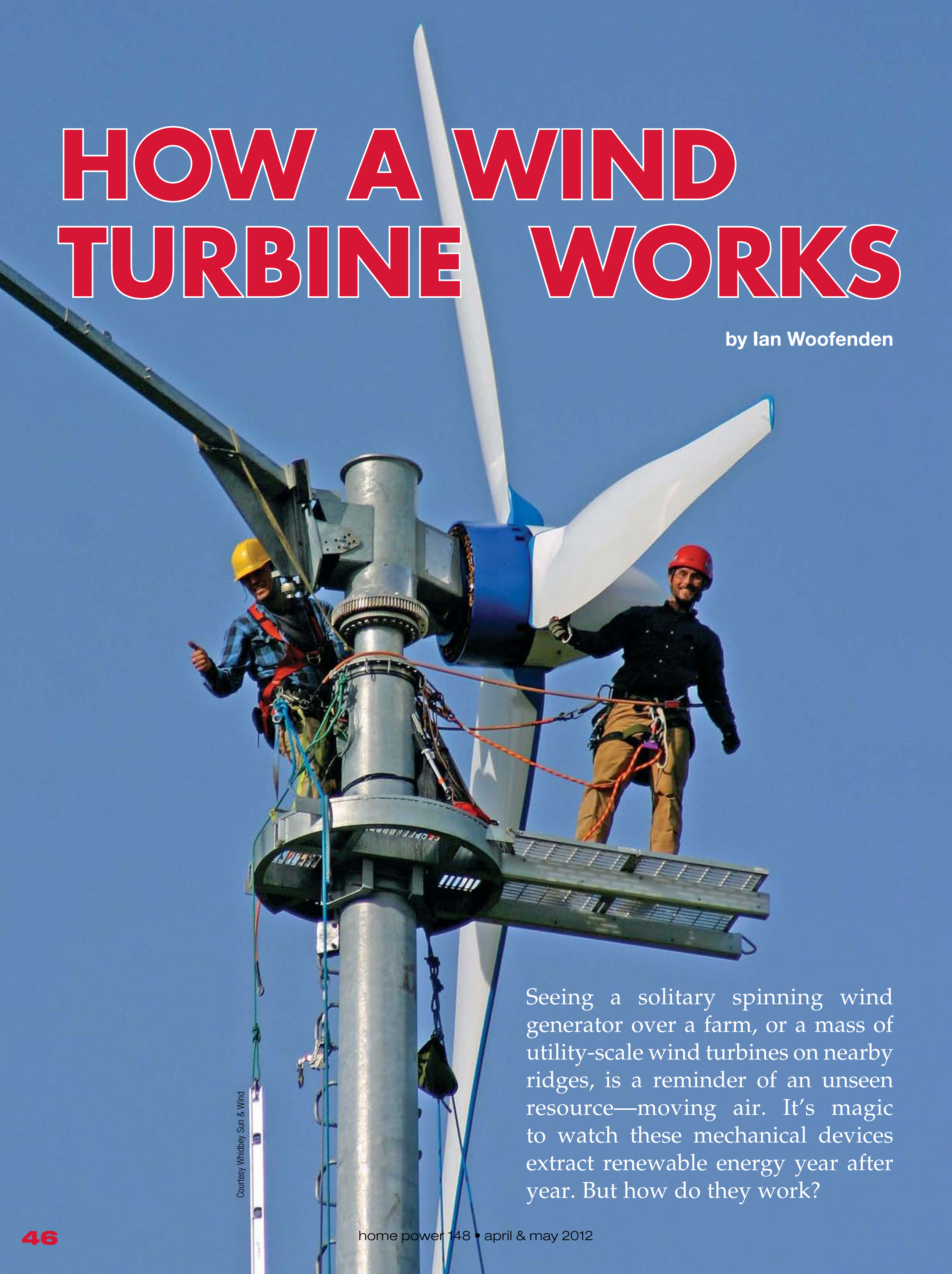
HOW A WIND TURBINE WORKS

by Ian Woofenden



Courtesy Whidbey Sun & Wind

Seeing a solitary spinning wind generator over a farm, or a mass of utility-scale wind turbines on nearby ridges, is a reminder of an unseen resource—moving air. It's magic to watch these mechanical devices extract renewable energy year after year. But how do they work?

Let's follow the energy flow, from the wind itself to electricity in your home, your batteries, or the grid. This article will help you understand the basic principles, components, and functions involved in a wind-electric generator.

What is the Wind?

Wind is created by differences in air pressure—globally, regionally, and locally. Uneven heating of the earth, water, and air create high and low pressure areas, and the air moves to equalize the pressure, moving from high- to low-pressure areas. The earth's rotation also affects the wind (the "Coriolis effect"), especially near the equator.

Local geographic features direct, intensify, diffuse, and otherwise influence the wind, with a variety of effects, such as the increase in wind speed over a ridge, or the up-/down-valley phenomenon we see in mountainous areas.

Remembering that wind is a *moving mass of air* can help you understand the physical demands of capturing it. Imagining this invisible resource as a colored mass can help you understand how hills, valleys, trees, buildings, and wind turbines interact with it.

Aerodynamics—Capturing the Wind

To capture wind energy, we have to stick something up into the wind that will convert the horizontal flow of moving air into some sort of usable motion. To pump water, we might want a vertical, reciprocating motion, but to make electricity, we need rotary motion.

The simplest conversion might look something like your basic anemometer—a series of half-cups (imagine half of a ping-pong ball) sticking out from a vertical shaft, and being pushed around by the wind. This is an easy way to make a shaft spin, but not the most efficient way to capture the energy in moving air. This strategy uses what we call "drag"—the wind is dragging the collector with it, and the device cannot go faster than the wind itself. The back side of the rotor is moving against the wind, which slows it down—so the efficiency is inevitably very poor compared with other methods.

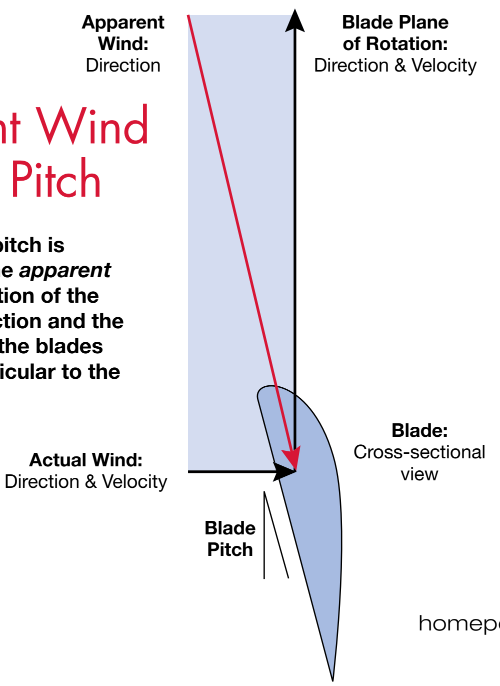
An anemometer is a drag device that can't spin any faster than the wind is moving. The upwind cup hinders it even further. Only through calibration does it register accurate wind speed. Drag devices are inefficient collectors of wind energy.

Most successful wind generator designs rely primarily on another physical phenomenon—"lift." We see this property in airplane wings, kites, sailboats, and other devices that use moving air to direct mechanical parts in a direction other than the wind direction.

The most common (read "most established, successful, and engineered") wind generator designs use two or more blades (usually three) on a shaft that turns on a horizontal axis (parallel to the ground). We call these "horizontal-axis wind turbines"—HAWTs. It may seem counterintuitive that these work, because the blades are spinning at roughly right angles to the wind. This works because the design of the blades relies mostly on lift, not drag. Once a wind turbine is spinning, the wind experienced by the front edge of the blade (called "apparent wind") is a combination of the natural wind direction and the wind created by the motion of the blade itself.

Apparent Wind & Blade Pitch

Optimum blade pitch is determined by the *apparent wind*: a combination of the actual wind direction and the wind created by the blades rotating perpendicular to the actual wind.



Determining Wind Speed

Figuring out what your wind resource is and the best place for a wind generator is vital and difficult. Without a reasonable estimate of the average wind speed at "tower top" (the height at which the turbine will sit), you'll be making a wild guess about the production of your wind generator. Estimating wind speed is much more complicated and volatile than solar energy predictions, since the resource varies dramatically between rooftop (where it is almost always negligible) to above the trees (where it may be worth capturing).

Short of a full-blown wind study—which is often hard to justify financially for residential sites—two primary resources are often used. First is wind mapping, which *might* give you reasonable data if you have the expertise to interpret it. Second is already-collected local data, which also needs interpretation, and can range from definitive to useless, depending on the source and duration.

See Access to learn more about wind site analysis. Meanwhile, remember that knowing the average wind speed on your site is crucial to predicting wind-generator energy production. And small differences in the wind speed can make a big difference in production. For instance, the energy available in a 12 mph wind is about 70% greater than the energy available in a 10 mph wind.

Courtesy Ian Woofenden

After reading this article, you'd be able to identify this as a three-bladed, upwind, direct-drive, permanent-magnet, side-furling wind turbine if you saw it in action.

Bust a Myth!

Are you wondering if the claims of a wind generator manufacturer, designer, or salesperson are legitimate or realistic? Apply a simple, generalized formula to get an idea of whether you're listening to a shyster or a reliable source.

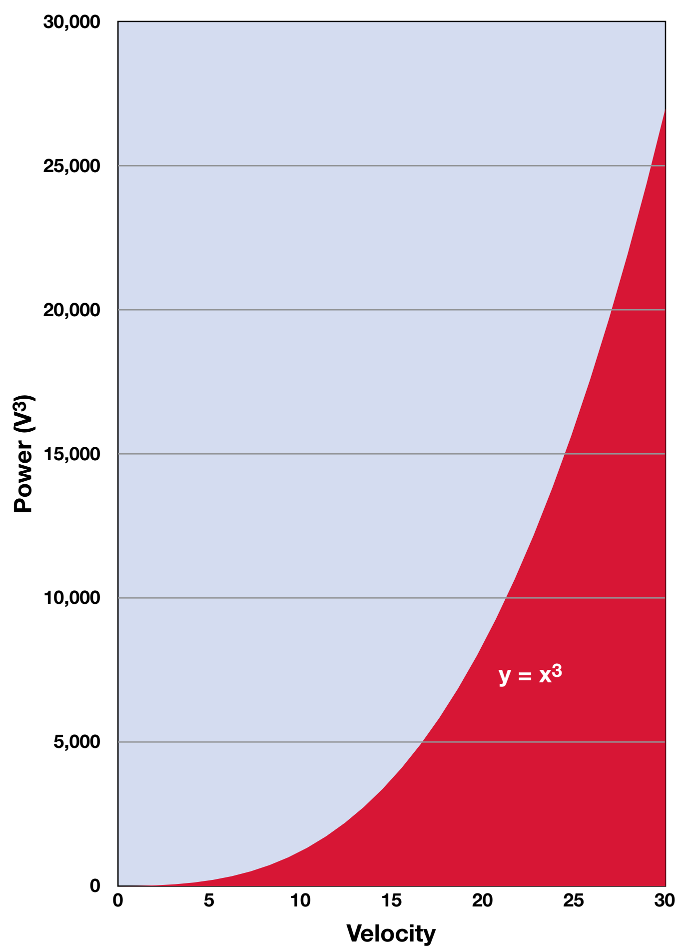
Take the average wind speed used for the claim, cube it, divide it by 240, and that will equal the approximate kilowatt-hours (kWh) per month per square foot of rotor, at the Betz limit. Cut that number in half and you'll have a good number for a well-designed residential turbine.

For example, in a 9 mph average wind speed, a turbine operating at peak theoretical efficiency (the Betz limit) would give you 3 kWh per month per square foot of collector area [(9 × 9 × 9) ÷ 240 = 3]. If someone is claiming that a 15-square-foot turbine will deliver 90 kWh per month, they are claiming twice what is physically possible, and about four times more than the best turbines on the market.

For a different method that comes to similar conclusions, see Mike Klemen's page at www.ndsu.edu/ndsu/klemen/Perfect_Turbine.htm

Many different blade designs and configurations have been tried over the years, and most don't work terribly well. There are good reasons that support the successful designs. Look around—from sailboat wind generators to utility-scale machines—and you'll see the results of decades of engineering development. More information on aerodynamics can be found in many places. Hugh Piggott's book, *Windpower Workshop*, offers technically accurate, concise explanations.

Power as a Cube of Velocity



Limits to Wind Energy

Wind is a *cubic* resource. The power available in the wind increases as the *cube* of the wind speed. If we shovel gravel twice as fast, we get twice as much gravel. If the atmospheric heat engine shovels moving air twice as fast, we get *eight* times as much energy (2^3, or 2 × 2 × 2).

This helps us understand wind generator design and siting. At the low end of the scale, it's important to know that anyone making significant performance claims at, say, 4 miles per hour is either clueless about the physics of wind or trying to pull the wool over your eyes. Do the math: Four times four times four is 64; 10 times 10 times 10 is 1,000. There just isn't very much energy at very low wind speeds. A wind generator doesn't start doing much until at least 10 mph.

On the other end of the scale, it's important to remember the forces we are dealing with. Forty times forty times forty

is 64,000. That's 64 times more energy than a 10 mph wind carries. You can see why wind turbines worth buying will protect themselves (govern) at 25 mph to 30 mph, shedding the rare high winds so they can stay alive for the next reasonable wind.

So there's a practical limit to how high of winds a wind generator is designed to capture. There's also a physical limit of how much of any wind you can capture. The Betz theorem states that you can only harvest a maximum of 59.3% of the wind before any attempt to take more will decrease what you get.

Think of it this way. A knife blade sticking up will take almost no energy out of the wind (only a little, due to friction). On the other end of the scale, a brick wall will try to take all of the energy out of the wind, blocking its path completely, but it won't turn any of it into useful motion. In the first case, the wind just passes by the "collector." In the second case, the wind backs up behind the collector, slows down, goes around, and just doesn't do any useful work.

Somewhere in between, there's a sweet spot where we can capture some of the energy in the wind without slowing it down too much. We need to allow enough moving air through the collector to ensure adequate flow, and not back up too much wind against our collector, diminishing the return. Betz says that the maximum is about 60%. In real-world applications, a well-designed, modern utility-scale turbine might hit 50%, while residential turbines fall more in the 20% to 40% range.

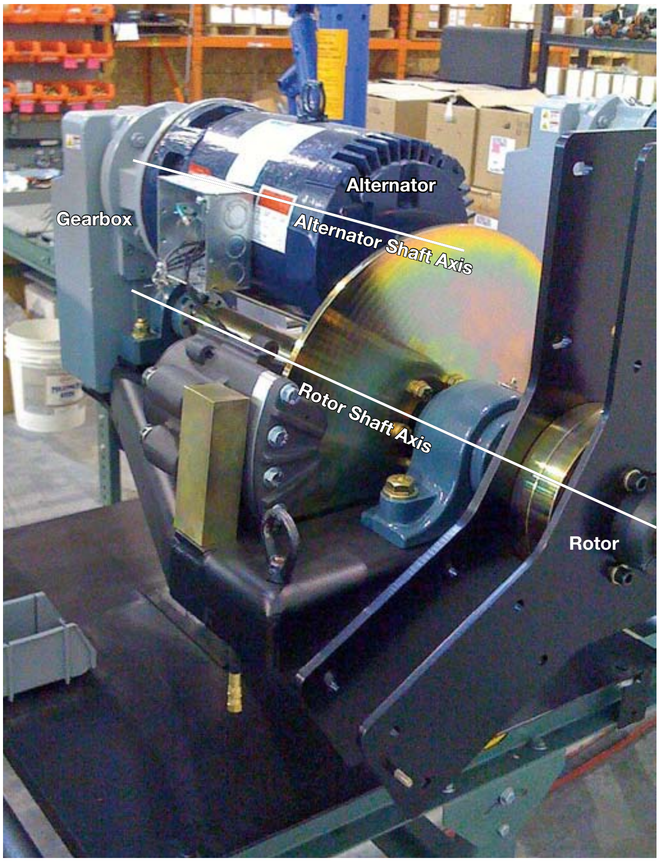
Mechanical Transmission

Once we've taken our portion of the energy of that moving air and turned it into spinning motion in a shaft, we still need to spin the alternator. That shaft is spinning in a certain speed range, generally peaking at 150 to 900 rpm, depending on the machine's size and its design. (Low-rpm machines capture the same amount of energy from the wind as faster-turning ones, but the slower pace incurs less wear and tear and makes less noise.)

We can use a generator that works in the same speed range as the spinning shaft coupled to the blades (called the "rotor"). These are "direct-drive" machines, and they are the simplest and most efficient, *if* the blades and generating device are well-matched.

In some cases, a gearbox is warranted, to increase the shaft speed from the blades to a higher shaft speed for the generator. On home-designed machines, this is sometimes a relatively inefficient belt and pulley arrangement, which will waste a lot of energy. On manufactured machines, a gearbox is used to increase the rpm for the generator. A gearbox adds to the mechanics of the system, which means more wear and maintenance—regular oil changes and, eventually, gear replacement. But it may be a worthwhile trade-off—if you have a good wind resource—to get good matching and for using conventional and economical generators, designed for higher speeds than we want our blades spinning. (Larger-diameter blades need to spin slower so they don't self-destruct from centrifugal force.) Although mostly we see direct drive in home-scale turbines and, historically, more gear-driven utility-scale machines, more home-scale wind generators are using gearboxes.

Ian Woofenden



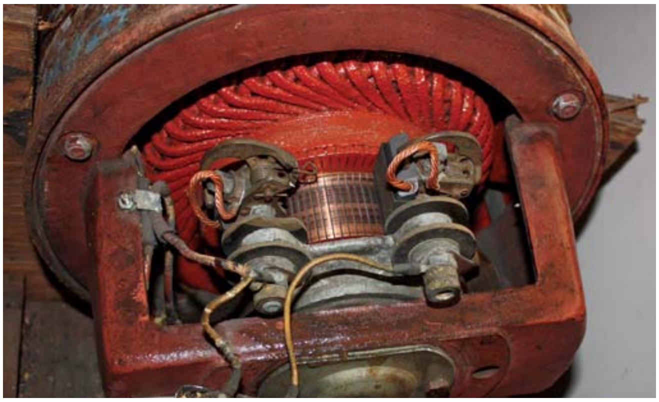
In some cases, a gearbox is necessary to optimize blade/rotor rpm with alternator rpm (also note this turbine's large disk brake).

Generating Devices

A generator or alternator moves magnetic fields past wire coils or vice versa, which makes electrons move in the wire. You may remember doing some science experiments as a child that showed this—it's not hard to measure voltage while waving a magnet past a loop of wire.

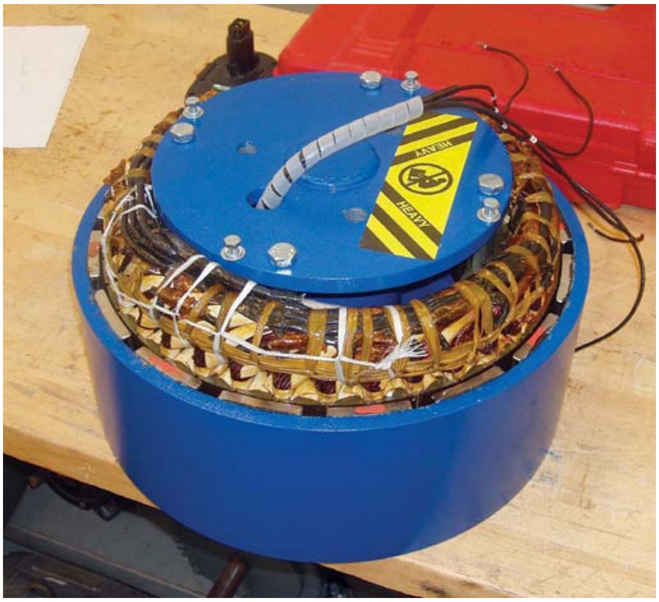
With generators, the goal is to move *lots* of magnetism past *lots* of wire to move *lots* of electrons. In one way or another, this is what generating devices are doing. There are three primary configurations, each of which has its own permutations and variations.

Wound-field alternators have a set of copper coils that are typically fixed (the "stator")—these are the coils we tap to harvest the electrical energy. They have another set of copper coils that are an electromagnet, and these coils typically spin past the fixed coils. These alternators are not very common today—we find them mostly in older designs. However, if they are well-designed, the magnetism ("field" or "excitation") can be very well matched to the wind speed. This means that the loading of the alternator can be matched with the available wind. One drawback of this design is that some of the wind energy is used to induce magnetism, so that energy is not available to make electricity.

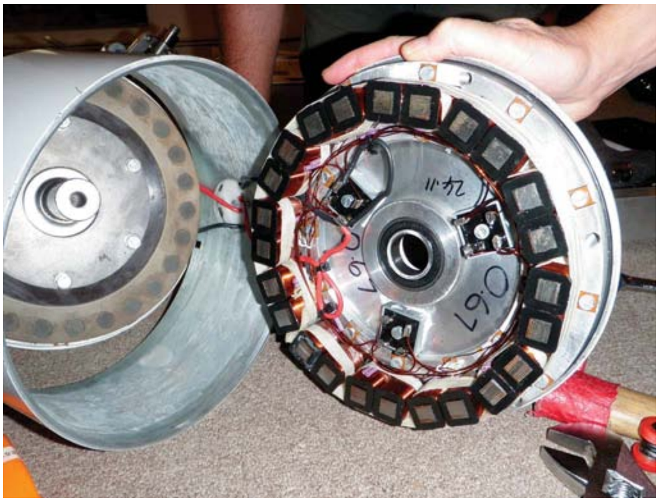


Courtesy Benjamin Root

This old Jacobs field-wound alternator requires brushes to supply energy to the electromagnetic field on the spinning rotor.



Permanent magnets on the outer rotor allow a simple brushless design. The windings are mounted on the inner immobile stator.



Courtesy Ian Woofenden (2)

This axial PM alternator has magnets on its rotor that spin past stationary coils face to face.

Permanent-magnet (PM) alternators follow the principle of moving magnetism past copper coils, but use permanent magnets—metallic materials that have stable magnetic properties. Older turbines use ferrite magnets; newer machines tend to use magnets of neodymium, a strongly magnetic material found primarily in China that commands very high prices.

PM alternators can be configured in a variety of ways, with coils spinning around magnets, magnets spinning around coils (most common), or in "axial" designs where the magnets and coils face each other in a disk-like arrangement, and the magnets typically spin.

Most home-scale wind turbines use PM alternators, which are simple, reliable, and economical. One minor drawback is that the magnetic strength is fixed, and not optimized for maximum power production at each wind speed. But lately, wind electronics engineers have been experimenting with voltage converters that adjust the balance between wind energy in and loading/generation, which overcomes this drawback somewhat to maximize production.

Induction generators use a cage, or conductive bars, spinning relative to groups of coils. A rotating magnetic field is created by feeding the stator coils with alternating current from the grid. This field interacts with the cage in the rotor to produce currents that make an opposing magnetic field, setting the rotor in motion. If the rotor is forced (by the wind) to turn faster than the magnetic field produced by the grid, then instead of drawing power, the device sends energy out to the grid.

These "generators" are the same as induction motors, and can be powered up by applying an electrical source to them. This is used in utility-scale and some home-scale machines to spin a turbine up to speed when the sensors and electronics show that there's enough wind to capture. Once the "motor" is going, the wind applied to the blades then pushes it beyond the amount of energy used just to generate energy.

One beauty of induction machines is that they need no inverter to connect to the utility grid. Electronics are necessary to facilitate and safeguard the connection, but the equipment is simpler and less costly than the inverter needed when you connect a wound-field or PM turbine to the grid.

Tail & Yaw

A wind generator needs to face the wind so that the blades are oriented to capture the wind efficiently. Home-scale horizontal-axis wind generators have a "yaw bearing," which allows the wind generator to swivel and face the wind—from whatever direction it is coming. This turning is called "yawing."

Yawing can be either active or passive. Larger home-scale machines and most utility-scale machines are active yaw, using motors and gears to turn the machine head around to face the wind, with wind vanes sensing the wind direction. Most home-scale machines have passive yawing, which uses the structural design of the machine to orient it into the wind.

Courtesy Ian Woofenden

Brushes transmit electricity from a yawing turbine down a stationary tower without twisting wires.

Courtesy Endurance Wind Power

With upwind machines (blades are upwind of the tower), a tail sticks out behind the machine, and the force of the wind on it pushes the rotor into a position facing the wind. With downwind machines (blades are downwind of the tower), the rotor acts as the tail to yaw the machine properly.

Slip Rings & Transmission

Because a wind generator yaws, but its tower is fixed, we need a mechanism to transmit the electrical output from the rotating portion to the fixed. Utility-scale machines and some home-built machines allow the wires to be twisted, and either a motor or the owner periodically untwists them. To transmit the energy on most home-scale machines, slip rings—two or more bronze rings that are on the fixed portion of the machine/tower, and graphite brushes that ride on these rings—create a connection for the energy and allow swiveling without twisting wires.

Wires relay energy down the tower to the electronics, batteries (if used), home, and/or utility grid. Transmission may be DC, or as wild, multiphase AC. There's not a great deal of difference between the two in efficiency or cost; it is higher voltage that gives better efficiency. A big advantage to running AC down the tower is that the rectifiers that convert AC to DC are at ground level, where they are easier to troubleshoot and replace if needed.

Courtesy Proven Energy

Governing

A well-designed machine must be able to govern—shed wind in some way to reduce high winds' force on the turbine and tower. Shedding wind energy also reduces the speed of the turbine, avoiding mechanical or even electrical failure. There are three primary methods of governing, with variations in each.

Furling tilts the whole blade rotor either to the side, up like a helicopter, or in a combination of those two, to reduce the area exposed to the wind. This is a very common governing strategy, and is effective and easy to build. They're a bit of an art to design, and governing systems of this sort can be sluggish in responding to high wind.

Courtesy Endurance Wind Power

Left: Centrifugal force on the blades works a linkage to change blade pitch on an old Jacobs generator. This complex but highly effective governor precisely regulates rpm.

Right: A side-furling governor uses the force of the wind on an off-center joint to pivot the blades out of the wind. In this case, mechanical furling is used to brake the machine during maintenance.

Pitch control changes the orientation of each individual blade in high winds, taking them out of their optimum aerodynamic position so they don't capture (or have to absorb) as much wind energy. This is typically accomplished with an arrangement with weights and springs. Governing happens incrementally as the rotational speed increases, and this strategy can be very precise, so it controls speed accurately and allows good production. This governing system may be more expensive than furling systems and is more prone to wear.

Stall is a speed-control method that relies on the inherent design of the blades, and results in poorer performance at high rotation. Stall regulation works by slowing down the blades in relation to the wind speed. If the rotational speed is constant (induction motor turbines, for example) and the wind speed increases, stall is inevitable—it just needs to be tuned to happen at the right wind speed.

Governing requires a delicate balance, regardless of what method is used, and relies on properly sizing and matching the various angles and offsets of the rotor and tail, the size and weight of blades, and the blade design. If any parameter is changed—making the blades longer or tail heavier, for example—you'll change the turbine's governing characteristics.

Braking

In addition to governing—which needs to happen automatically in high winds—wind generators need the ability to be stopped manually. We do this when we: need to repair them; think there's some problem; are expecting too-high winds; or when we simply don't need the energy (for instance, with a seasonal residence or a long vacation).

Mechanical brakes can be drum brakes or disk brakes, and are often activated by a hand winch at the tower base. A few turbines use manual furling with a tower-base winch to swing the rotor out of the wind—this at least slows it, if it doesn't fully stop the rotation.

Dynamic or electrical braking shorts the DC or wild AC output, stopping the turbine's rotation. Depending on the alternator design and wire run, this can be very effective. In other cases, it's iffy, and may not stop a machine in high winds, or hold it once stopped. Neodymium magnets have a more reliable effect for dynamic braking. Make sure you understand the limitations of dynamic braking for your particular machine.

Dynamic braking uses the alternator's electromagnetism against itself by shorting all three wires together.

Courtesy Ian Woofenden (3)

Electronics

A crucial part of a wind generator system is the electronics needed. Each machine will have its own electronic systems, which may include:

- Rectification to convert AC to DC.
- Maximum power point tracking (MPPT) to get the most output from the wind generator by matching the charging curve to the wind power curve. This relies on a programmed wind power curve for the particular turbine used.
- Charge controller to regulate battery charging (if used).
- Metering and data logging to monitor system performance.
- Circuit protection (breakers) is often included.

Making a Wise Choice

Understanding how a wind generator functions can help make wise buying and design decisions. Although wind generator specifics are discussed here, what you need is a whole system, which includes tower, transmission wire and conduit, electronics, and more. You need all the appropriate components, they need to be of high quality, and they need to be matched to each other. Usually, it's best to buy everything as one package to avoid surprises and problems.

Tapping that flow of moving air can be a lot of fun, but I'm here to tell you that it ain't easy. If you approach it sloppily or with a nickel-and-dime attitude, you're more likely to get poor and costly results. Investing in a good product and system and installing it with attention to detail will give you dependable renewable energy, now and over the long haul.

Access

Ian Woofenden (ian.woofenden@homepower.com) has been using, installing, fixing, consulting, and teaching about wind generators for more than 25 years in the Pacific Northwest. He is the author of *Wind Power for Dummies*, and one of the founders of the Small Wind Conference (www.smallwindconference.com).

Resources:

"Anatomy of a Wind Turbine" by Ian Woofenden & Hugh Piggott in *HP116*

"Estimating Wind Energy" by Hugh Piggott in *HP102*

"Wind Power Curves: What's Wrong, What's Better" by Ian Woofenden in *HP127*

"Understanding Wind Speed" by Ian Woofenden in *HP143*

"Estimating Obstruction Height" by Ian Woofenden in *HP141*

"Wind Turbine Transmission Wire Sizing" by Hugh Piggott in *HP134*

"Wind Electric System Basics" by Ian Woofenden in *HP110*

"Site It Right! An Interview with Wind Energy Consultant & Installer David Blecker" by Ian Woofenden in *HP115*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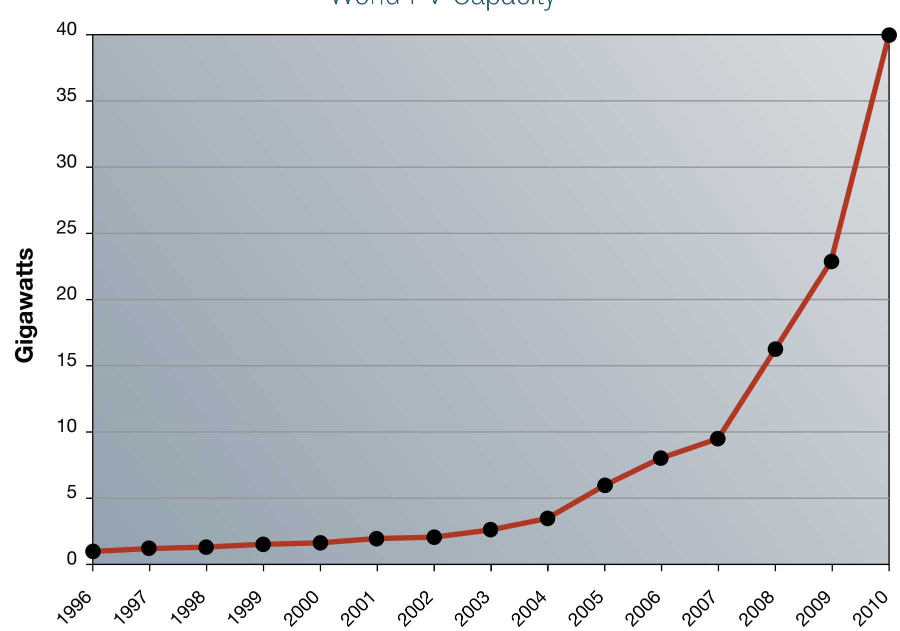
PV MARKET TRENDS

by Justine Sanchez

Since the 1950s, solar electricity has grown in leaps and bounds: from research laboratories to supplying power for space applications; from backwoods, off-grid homes to large utility-scale systems. Similarly, the cross-section of industry folks now spans the gamut: from lab coats and glasses to tie-dyes and sandals, to Carhartts and boots, and, most recently, to suits and wingtips.

While exciting, navigating such rapid change has been challenging for many in the PV industry. However, the end result is that, like any developing industry, the market forces that propel these changes are making solar affordable and more attainable than ever before.

World PV Capacity



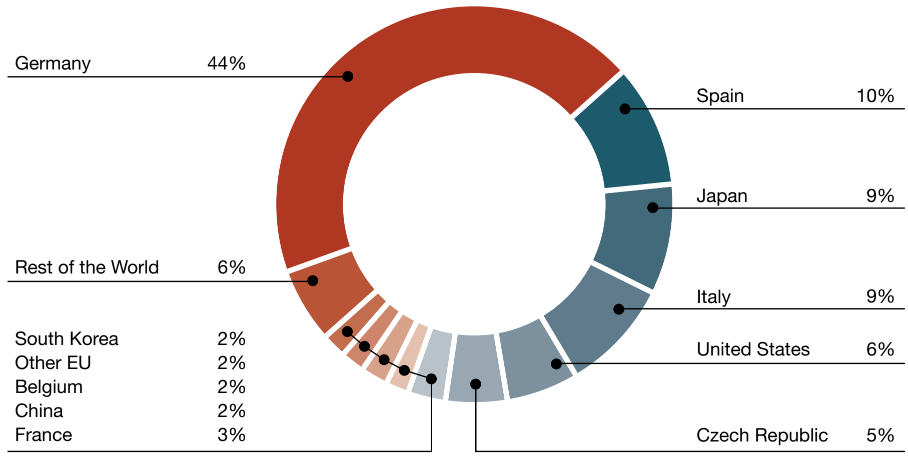
Source: PV News & EPIA

Five Years Back

The PV industry has been enjoying steady growth. From 1996 to 2006, the worldwide installed capacity grew tenfold—from 0.7 gigawatts (billion W, or GW) to 7 GW. It is over the last five or so years that incentive programs around the world, combined with lower equipment costs, have enabled exponential growth. From 2006 to 2010, global installed capacity went from 7 GW to 40 GW. (In the United States, installed capacity grew at a slower pace, from 0.6 to 2.5 GW.) In 2011 alone, another estimated 23.8 GW was added globally. Of that, 7%—about 1.7 GW—occurred in the United States. According to the Solar Energy Industries Association (SEIA), in 2010, the overall U.S. solar industry grew to $6 billion, up from $3.6 billion in 2009 (the 2011 estimate was not available at the time of printing). In the United States, it's estimated that the industry employs more than 100,000 people at 5,000 businesses.

The incentive programs that have spurred this worldwide growth include feed-in-tariff (FIT) programs, which pay a premium price per kWh for PV-produced energy. FIT leaders include Germany, Spain, Japan, and Italy. While a handful of U.S. communities have adopted FIT and other production-based incentives, they're relatively new in the United States. Instead, tax credits, grants, and rebate programs that reduce upfront system costs have historically dominated in the United States. During that same time, module prices have declined from about $5 per W in 1995 to around $1.50 now.

Total Installed PV Capacity Through 2010, By Country



Source: EPIA, BMU, IDAE, GSE, KOPIA, CREIA

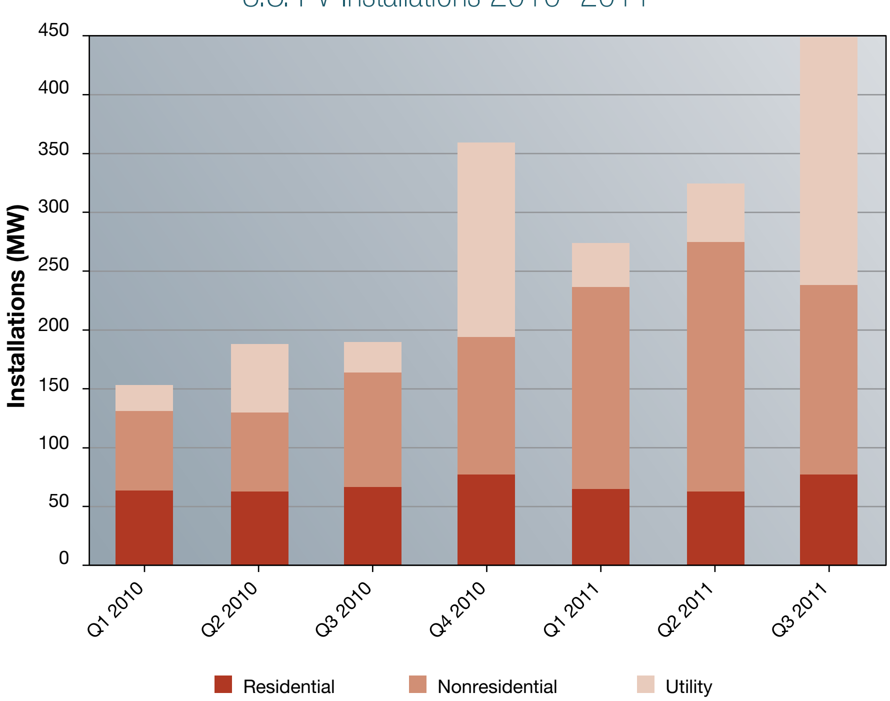
The Present

The PV industry is maturing—and experiencing growing pains. PV manufacturers attempting to meet the rapidly growing demand for modules quickly opened new manufacturing plants and increased production at existing facilities. Unfortunately, increased module production coincided with the overall economic downturn, fluctuating incentive programs, and less expensive modules available from overseas—particularly China (see "U.S./China Trade Dispute" sidebar).

This led to an enormous module surplus, outstripping demand to cause a drop in module prices. An industry shakeout is underway—several U.S. solar companies declared bankruptcy in 2011, including Beacon Power, Energy Conversion Devices, Evergreen Solar, Solyndra, and SpectraWatt. Meanwhile, production cutbacks or reorganizations have been announced by many companies, including Conergy, Day4Energy, REC Group, SolarWorld and SunPower.

Possibly as a result of some of these high-profile PV manufacturing company closures (namely Solyndra, which received $535 million in government loan guarantees before

U.S. PV Installations 2010–2011



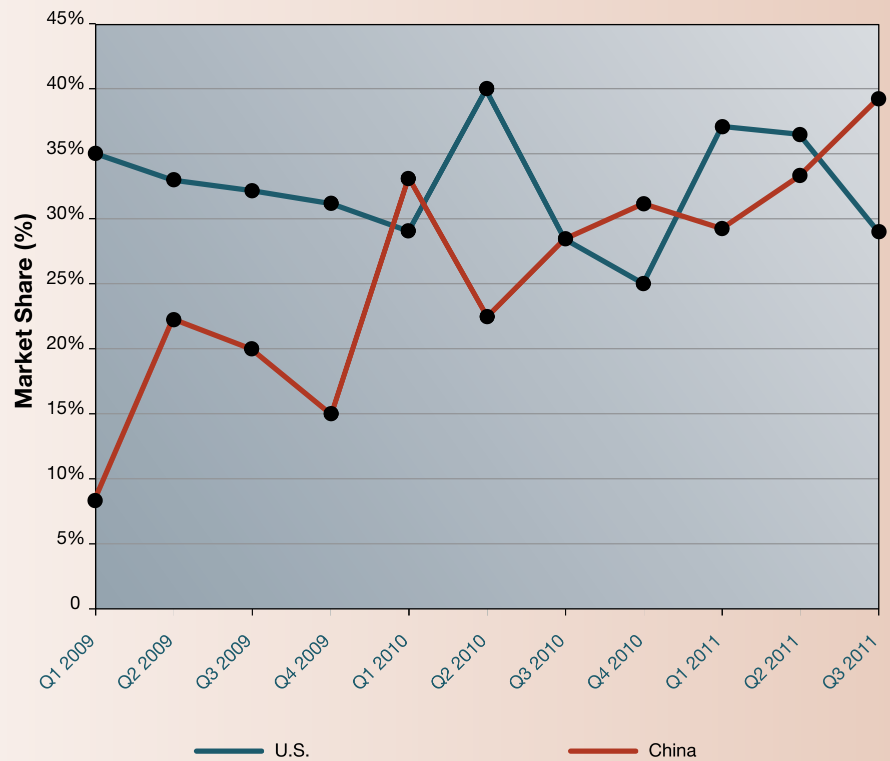
Source: GTM Research & SEIA

U.S./CHINA TRADE DISPUTE

In October 2011, SolarWorld and six other unnamed U.S. solar manufacturers formed the Coalition of American Solar Manufacturers (CASM) and filed an official claim with the U.S. Department of Commerce and the International Trade Commission (ITC) claiming that China was dumping PV modules in the United States and providing unfair subsidies to its solar industries. A preliminary conclusion in December by the ITC said it had found a "reasonable indication that a U.S. industry is materially injured" by PV modules from China "that are allegedly subsidized and sold in the United States at less than fair value."

The next step will investigate whether or not to take action, which could include providing compensation measures and imposing protective tariffs on Chinese modules. According to the U.S. Commerce Department, these tariffs could be anywhere from 50% to 250%. The deadline for a preliminary decision (as of the end of January) is set for March 27, 2012.

U.S. vs. China-Made PV Modules Installed in California*



*Source: California Solar Initiative & GTM Research

Greentech Media's *Solar Power Year in Review 2011* says that "it's no surprise that the cheapest modules are being installed in larger quantities than more expensive, domestically produced products." Although the graph only depicts California, additional analysis—including data from other major state markets—shows that Chinese products accounted for 41% of all U.S. residential and commercial installations. In comparison, about 20% of modules installed in United States during that same time were American-made. The review also states that "the percentage of Chinese modules used in U.S. installations is projected to grow in the first quarter of 2012 as Chinese manufacturers aggressively move product into the United States to avoid potential tariffs and help developers complete projects at pre-tariff price points."

Much of the PV industry is divided over the trade dispute. Many fear that imposing tariffs will negatively impact the viability of future PV projects, stalling the momentum of the industry. A counter-CASM group—the Coalition for Affordable Solar Energy (CASE)—has formed and is comprised of other solar businesses, including several large PV integrators, balance-of-system (BOS) component manufacturers, retailers, and module manufacturers (including some based in China). CASE contends that the solar project development industry and the silicon manufacturing industry could lose even more jobs if CASM's actions result in tariffs against Chinese modules. See "The Circuit: News & Notes" in this issue for more information on the U.S.-China trade dispute.

failing), the latest blow to the U.S. PV industry was losing the 1603 treasury program, which was allowed to expire on December 31, 2011. This program, created under the American Recovery and Reinvestment Act of 2009, allowed federal grants to be given for commercial, industrial, and agricultural RE projects in lieu of the 30% tax credits.

While SEIA and other solar advocacy groups continue to push for an extension of 1603, they are also focusing on state-level policies and legislation. SEIA stated, "State efforts will entail a number of different policy efforts, including net metering, a financial tool for recognizing [the] value of distributed generation on the grid, and removing barriers to grid interconnection and permitting."

A Silver Lining?

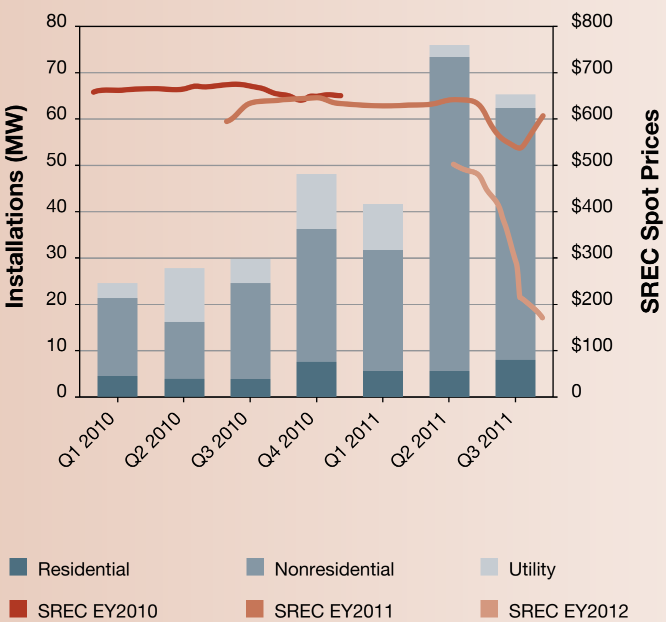
PV module prices are at a historical low, due to the oversupply. As a result, grid parity—the price at which PV-produced kWh, without subsidies, is equal to or less than electricity from conventional sources—is being approached or even

FLUCTUATING PV INCENTIVES

Financial incentives are intended to level the playing field between conventional and renewable energy sources, and to spur industry growth. These programs make RE projects much more affordable, enabling the market to grow more rapidly—but they can also create a subsidies-dependent industry. While conventional energy suppliers also depend on subsidies, PV incentive programs have experienced significant fluctuations. One negative result has been to slow the growth of PV markets.

Many FIT programs, such as those in Germany, Italy, and Spain, have decreased payments in efforts to stabilize their overheated PV markets. At the state level, rebate programs (such as those in Arizona, California, and Colorado) have been significantly cut or suspended—often due to demand rising more quickly than expected and an early exhaustion of earmarked funds.

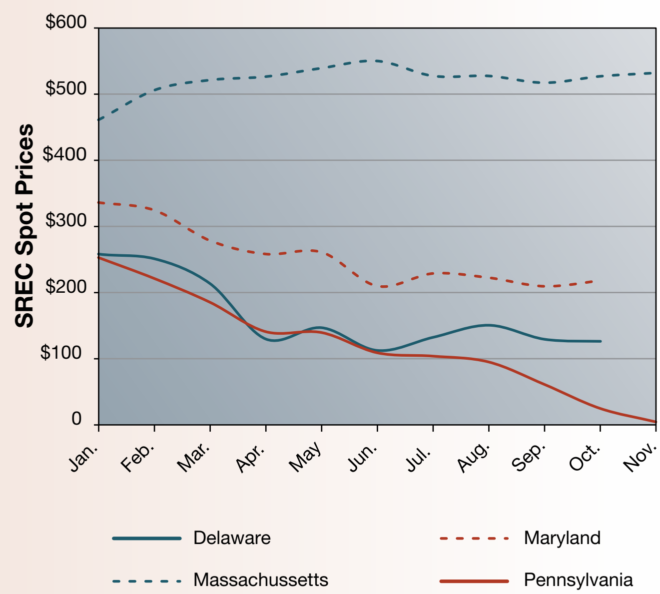
New Jersey PV Installations & SREC Prices



Source: U.S. Solar Market Insight (GTM Research & SEIA)

SREC 2011 Spot Prices

This graph shows SREC spot pricing trends with spot market (bid-based) agreements. These SRECs are sold every month or quarter at the highest current price. In contrast, long-term SREC contracts provide PV system owners a fixed price per SREC for a multiyear term. Contract pricing will be lower due to the uncertainty of future SREC market prices.



Source: PVNews (GTM Research)

New Jersey's FIT program stimulated megawatt-scale PV projects to give that state the second-largest installed PV capacity in the United States. However, this program also created an oversupply of solar renewable energy credits (SRECs), causing the SREC spot pricing to drop from about $500 (in 2011) to currently around $200 (the New Jersey SREC "Energy Year" runs from June 1 through May 31). A similar scenario played out with a FIT program in Pennsylvania, although on a smaller scale, with SREC prices dropping from a high of about $300 (in mid-2010) to about $10 at the end of 2011.

reached in areas with higher utility rates, such as Hawaii. John Farrell, senior researcher at Institute for Local Self-Reliance and author of *Solar Grid Parity 101*, estimates that by 2016, PV systems in California and New York will join Hawaii in achieving grid parity. And Andrew Beebe, chief commercial officer at Suntech, says that with some scenarios at the utility scale, it's already been achieved. "In some cases," says Beebe, "utility installations are now projected to deliver electricity over 25 years at less than $0.10 per kilowatt-hour, without government subsidies." The near future will likely reflect a shift, from PV companies chasing subsidies to those seeking economically sustainable investment projects, such as large-scale utility systems that are cost-competitive with conventional energy.

The PV Future

Shayle Kann, managing director at Green Tech Media Research, says that the "U.S. solar [industry] is entering 2012 with a sense of cautious optimism," with three questions on the mind of everyone in the market:

The Future is Now

One thing we have learned from watching various PV incentive programs come and go is if you have an incentive available, act sooner rather than later. While state tax credits for PV systems tend to be fairly stable, many utility and state-run incentive programs have started to decrease their incentive awards.

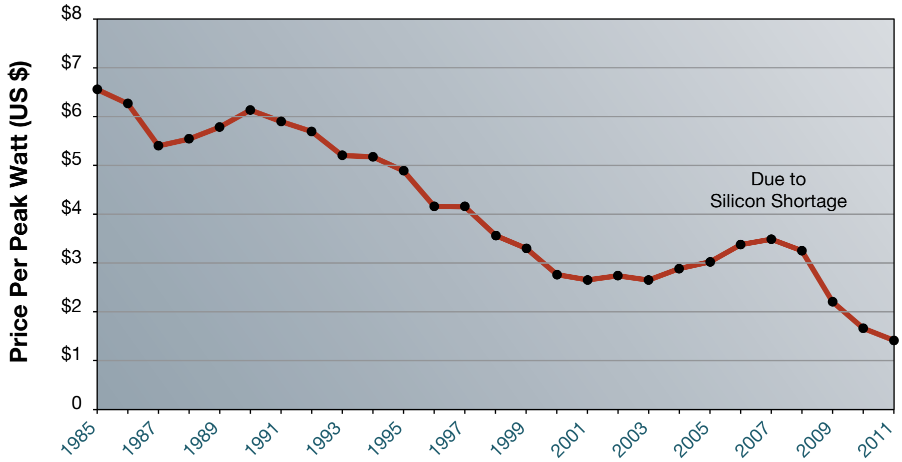
We wanted to know where relatively stable incentive programs were still in place, so we turned to Amy Heinemann, a senior policy analyst at the North Carolina Solar Center/DSIRE, who provided us this list.

- Energy Trust of Oregon's Solar Electric Buy-Down Program is consistently open • http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=OR23F&re=1&ee=1
- California Solar Initiative's PV Incentives are pretty transparent with step-downs after capacity targets are hit • http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA134F&re=1&ee=1
- MassCEC Commonwealth Solar II Rebates open and close several times per year, but these "blocks" are scheduled • http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=MA71F&re=1&ee=1
- NYSERDA's PV Incentive Program, as well as their other customer-sited tier incentives, are pretty stable through 2015 • http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=NY10F&re=1&ee=1
- Maryland's Clean Energy Grant Program for residential solar is adjusted frequently, but is consistently available • http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=MD14F&re=1&ee=1

As far as SREC programs go, spot pricing in Massachusetts has been remaining high (~$500 per SREC). SREC pricing in Washington, DC, has been on the rise (currently ~$275 per SREC).

Even with reduced incentives, with PV modules offered at some of the lowest prices we've seen, now's still a good time to implement your PV system plan.

Worldwide Module Price Trends



Sources: 1985-2010 data from Paula Mints, Principal Analyst, Solar Services Program, Navigant; 2011 numbers based on current market data

- What will be the impact of the 1603 treasury program expiration?
- Can other states' emerging commercial markets ramp up, as major markets like California, New Jersey, and Pennsylvania trend downward?
- How will the trade petition against Chinese PV imports impact the market?

Regardless of all of the industry shake-ups, the sun still comes up each morning—along with our choice to take advantage of its free energy. When I first started teaching in the solar industry, one of my favorite things about it was our focus on individuals choosing to take power into their own hands, and not needing to wait for anyone (i.e., the utility or government) to do it for them. We installed a full system with each class we taught, and it was exciting, empowering, and fun. There were no subsidies back then, and the cost for a grid-tied PV system was about $10 per watt, installed. Each new installation felt like a personal victory.

We still have that choice, but at about half the cost (and, for now, we still have a 30% federal tax credit). So, my forecast, from a consumer and end-user perspective, is that things still look pretty sunny.

Access

Justine Sanchez (justine.sanchez@homepower.com) is a technical editor with *Home Power* and an instructor for Solar Energy International. She is certified by ISPQ as a PV Affiliated Master Trainer.


Nature provides us with the gift of energy through the sun, but unfortunately, nature's wrath may not be all that friendly to your PV system under stressful conditions. Snow, wind, extreme heat or cold, and seismic activities can wreak havoc on underengineered, underdesigned and insufficiently tested racking structures. Only UNIRAC solar structures have been engineered and third-party tested to withstand the harshest of elements and events for a long and enduring service life. Complies with IBC, IRC, ASCE-7-05, ADM, AISI, AISC, NEC and UL. For the highest level of engineering and construction with the lowest cost of ownership in the business, Unirac is the 24/365 solution for performance in and out of the sun. Visit unirac.com for more information.
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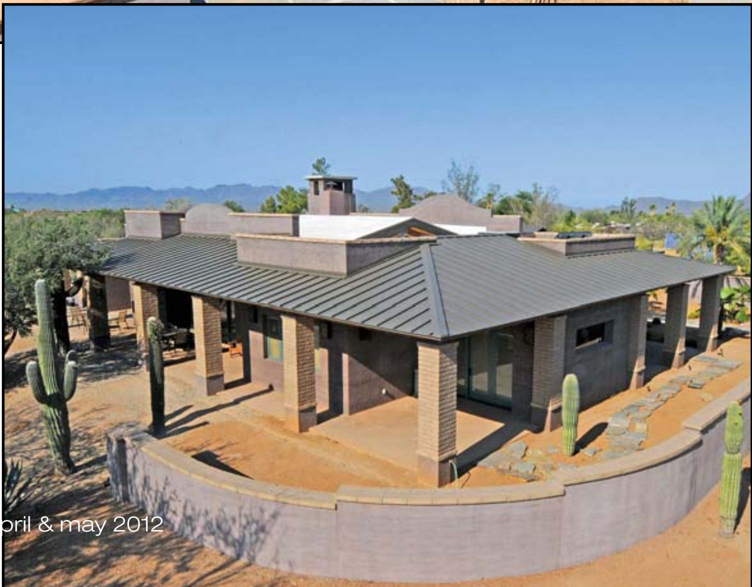
High-Desert Performance

Designing & Constructing Del Fierro

Story & photos by Edward Marue



Del Fierro is a home designed from the ground up to be an upscale, energy-independent, passive solar residence. The intention was to create a structure capable of lasting centuries and one in which interior spaces can be periodically updated as technology, lifestyles, and trends change. The theory is that this would result in lower lifetime costs with less overall environmental impact than a similarly sized conventional home. Much of the project was experimental with an eye on future scaled-down versions for affordable housing projects.

Thanks to reduced cooling loads, 5,440 watts of photovoltaic modules on dual-axis trackers can provide most of the Marues' electrical energy needs.

Launching the Project

I tackled my first energy-efficiency project on my own 1980s-era home in 2000 by weatherizing; upgrading to more efficient appliances and a high-efficiency HVAC system; using CFL lighting; and applying energy consciousness. Although I reduced energy consumption by about 40%, I concluded that there's a limit to making an older home highly efficient. To get to the next level, I needed to start from scratch. This is particularly true in the postwar desert Southwest, where the housing techniques—2-by-4 stick-frame construction, with minimal or no wall insulation—reflected a time when energy was relatively cheap.

After studying passive solar design, construction techniques, and materials, I was frustrated to find that little was written about the topic specific to desert climates. Most passive solar technology focuses on heating and retaining heat. While the physics of heat conduction and convection apply similarly to cooling and heating, the effects of the sun's radiation play a significantly more important role in cooling design. In the summer in the desert Southwest, exposed surfaces can frequently reach temperatures in excess of 150°F, so keeping out the heat is more important than in other climes.

The Del Fierro home in the high desert of Tucson, Arizona, combines design features that maximize passive cooling and reduce mechanical heating and cooling requirements.

What is Lava Concrete?

Developed by Paul Schwam, a local architect/builder, lava concrete (LC) is a made from a porous, lightweight volcanic aggregate called scoria, which is mixed to form a self-supporting semi-fluid. When cured, it becomes a lightweight stone. Scoria's porosity holds pockets of water to help cure the cement. Once the water has evaporated, tiny air cavities remain to provide sound and thermal insulation. LC is used for foundations, floors, walls, and roofs. It provides the structure, insulation, thermal mass, and the finish—all in a single and seamless, raw-to-finish process.

Because LC starts as an easily workable semifluid, any shape or detail can be added to architectural elements—planes and curves; textures and details; and accessories, such as fireplaces, furniture, moldings, drip edges, window/door trim, niches, and artwork. Builders can integrate details such as ledgers, beam pockets, utility raceways, and block-outs—eliminating material and labor steps along the way.

LC helps optimize the sequence of construction. Electrical, plumbing, and other utilities install first into empty forms. The structural wall is cast as the final step. The permanence of the concrete and stone structure will remain fresh, even with periodic future upgrades to utilities, internal layout, and furnishings.

The lava concrete mix is pretty dry, and needs minimal hand work.

The thermal mass and trapped air space of lava concrete lends itself to tempering the thermal swings of a desert climate.

Right: Because lava concrete starts as an easily workable semifluid, any shape or detail can be added to architectural elements.

Below right and lower right: Scaffolding is set up to accommodate pumping lava concrete in lifts.

After site preparation and installation of subgrade utilities and footings, rebar and forming went directly on top of the concrete foundations. Forms were constructed from treated 4-by-8 plywood with cut-outs for window and door openings. Once utility raceways were installed, pouring was done by three people: one operated the delivery chute; another tended to the formed details, lightly compacting the LC to assure no voids; and the third monitored the mixing machine and conveyors.

The mixing machine was key to the process and specifically designed to combine the cinder sand (scoria) and Portland cement with injected water to form a relatively dry mix. Conveyors delivered the LC to the forms, where it was poured 2 to 8 feet high in lifts. A 24-foot-tall wall may require three to 12 pours.

The lava sand used was a deep red color, from Flagstaff, Arizona. Blended with about 20% Portland cement, the poured fill cures similarly to regular concrete. Sandblasting the surface restored much of the natural volcanic color that was grayed by the cement. Once sealed (water-based Okon was used for Del Fierro), the exterior requires no additional maintenance.

One of the advancements developed during our project was a post/anchor bolt system, which eliminated the need for precast anchors, and greatly simplified the hand-off to other trades. It allowed operations, such as attaching ledgers, to be done simply by pre-drilling and insertion of large bolts. During construction, tests were performed on the strength of the attachment system, under the supervision of structural engineers to comply with the local building department. Windows and doors were installed in the blanked-out openings and secured with polyurethane foam and an LC-based grout.

Due to the complexity and volumetric size of this house, the cost per square foot for the basic shell was about $85. For modest-scale projects, LC can be constructed more cost-competitively.

The cooling tower uses evaporative phase-change and "reverse-chimney" convection to draw cool air into the house.

For keeping a home cool, it is critical to reduce its exposure to the sun, keeping the surface temperature of the shell as low as possible. This reduces thermal conduction through the envelope and minimizes charging of thermal mass. This can be accomplished by shading with overhangs, vegetation, the use of reflective coatings, light colors, and radiant barriers. Compromises for cooling over heating are made, since saving energy on cooling was the deciding objective. Tucson has almost twice as many cooling degree days (the number of days where mechanical cooling is needed) as heating degree days (2,954 vs. 1,678). Compare this to Ann Arbor, Michigan, which has 7,864 heating degree days and 289 cooling degree days, and you'll see the drastic differences in passive design requirements.

An Inherently Cool Design

Readily available earthen-based building materials, such as adobe and rammed earth, have been used in the Southwest throughout history. Modern performance-driven designs fully benefit from their inherently high thermal mass, fire resistance, and durability. I originally intended to use rammed earth, which involves compressing a mixture of earth, chalk, lime, and gravel (and sometimes a cement stabilizer). But at 3,450 square feet, costs for rammed earth were prohibitive due to the volume and complexity of the house, with its high ceilings, parapets, and intricate architecture.

A member of my design team introduced me to lava concrete (LC), a lightweight cast-in-place concrete made from volcanic cinder sand, very abundant in Arizona and other parts of the world. The construction is similar to casting rammed earth, but much less labor-intensive. Once cured, the steel-reinforced structure is strong and considerably more durable than rammed earth or other earthen building systems. With an R-value of 3.27 per inch, our 18-inch-thick walls would be nearly R-59. The LC also provides thermal mass and soundproofing. The inside was finished with a natural clay plaster from American Clay, which also contributes to the home's thermal mass.

A cooling tower provides evaporative cooling and much-needed humidity in the dry months of March through June. A mister injects moisture at the top of the tower, wherein the cooler, dense air falls by gravity, displacing warmer household air out through open windows at each end of the house, and a small electric fan augments the airflow. The cooling tower also works at night when the outside ambient air temperature is cooler than the displaced inside ambient room air.

Another passive cooling technique—deep (8- to 12-foot) overhangs—help shade south- and west-facing walls and windows in the warmer months. Helping overall building efficiency, the roof includes a 2-inch, R-14 sprayed-on layer of urethane foam over a double layer of OSB over I-joists and trusses filled with loose-fill fiberglass insulation, for a value of R-45 to R-60. A white polymer reflective paint was sprayed over the urethane. Pella InsulShield triple-pane, argon-filled, low-e windows and doors retard heat transfer.

PV Tech Specs

Overview

System type: Batteryless, grid-tied solar-electric

Location: Tucson, Arizona

Solar resource: 9 average daily peak sun-hours (for dual-axis tracking system)

Record low temperature: 6°F

Average high temperature: 100°F

Average monthly production: 1,104 AC kWh

Utility electricity offset annually: 87%

Photovoltaic System Components

Modules: 32 BP SX170B, 170 W STC, 35.4 Vmp, 4.8 Imp, 44.2 Voc, 5.0 Isc

Array: Four eight-module series strings, 5,440 W STC total, 283.2 Vmp, 19.2 Imp, 353.6 Voc, 20.0 Isc

Array combiner box: Square D HU361RB

Array installation: Array Technologies AZ-225 Wattsun dual-axis trackers on pole mounts

Inverters: Two Xantrex GT 3.0, 3 kW rated output 600 VDC maximum input, 195-550 VDC MPPT operating range, 240 VAC output

System Cost

Initial cost: $45,064

Less incentives: $16,320 TEP utility rebate

Final installed cost: $28,744

Major Load Information

Space heating: Electric forced-air heat pump

Cooling: Electric forced-air heat pump; evaporative cooling tower (electric fan)

Water heating: Solar hot water system, with propane backup

Cooking: Electric

Clothes drying: Electric

Refrigeration: Electric

Mechanical Systems

All appliances (range, oven, microwave, dishwasher, refrigerators, washer, and dryer) are Energy Star-rated, and CFL and LED lighting is used throughout.

Two 40-gallon batch solar water heaters are backed up with two Bosch 2400E LP on-demand propane-fired units. The SHW system can either feed the backup unit or send the solar-heated water directly to the house. We have it route through the backup units, which are temperature-modulated.

When needed, mechanical cooling and heating is provided by three high-efficiency (16 SEER-rated) fresh or recirculated air-source heat pumps, 2-, 4- and 5-ton units, respectively.

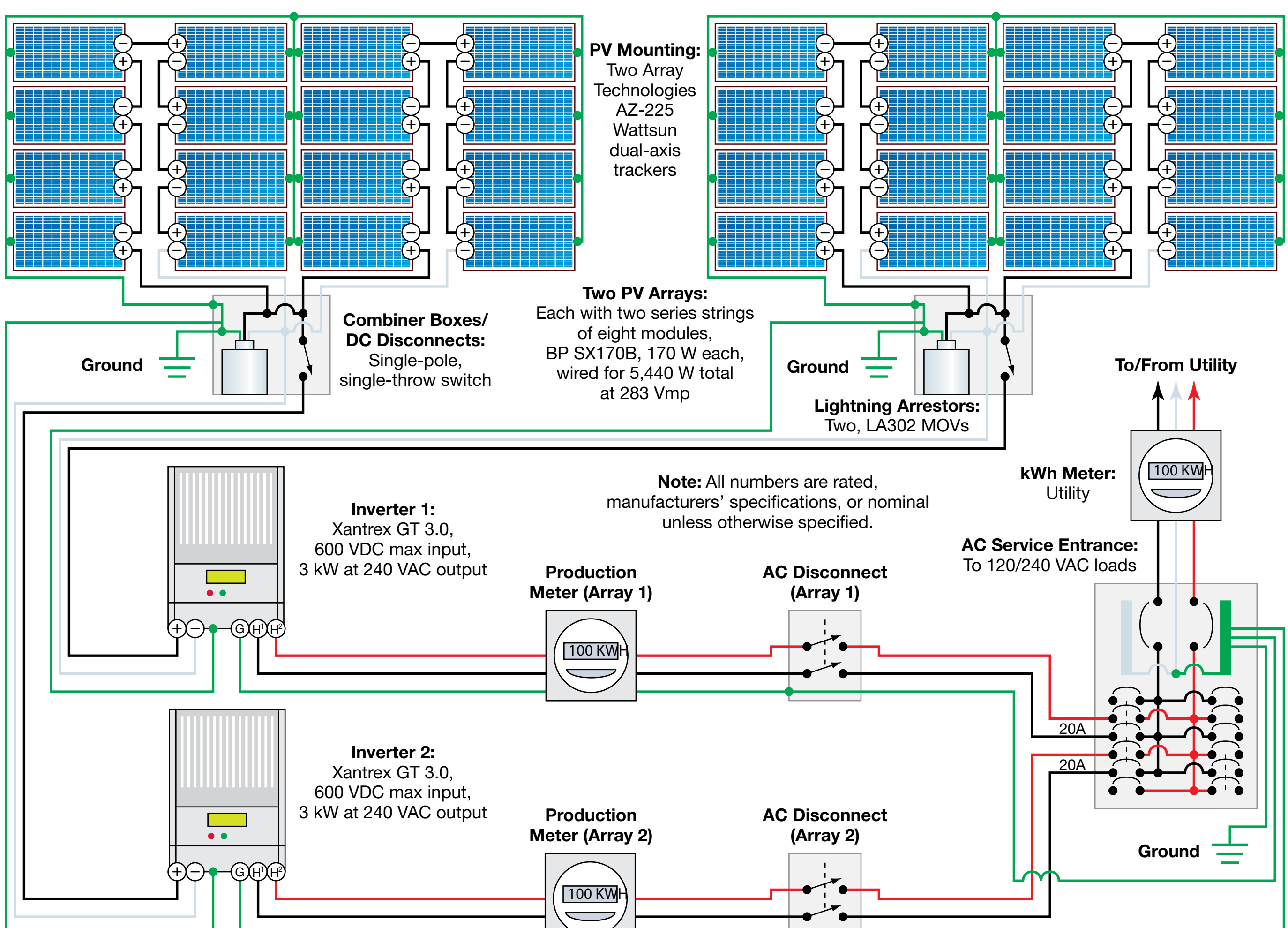
A grid-tied 5.44 kW, dual-axis, tracked PV array provides most of the home's electricity. (The array size was based on the most PV modules I could get on a pair of Wattsun AZ-225 trackers.) PVWatts calculates that our system should generate 13,253 kWh annually. Since PV module prices have dropped, I plan on adding a ground-mounted PV system to cover the property's entire electricity requirements, including the guest house and shop.

For the first year of data gathered, ending in July 2010, our usage exceeded our original energy budget. During that

Two identical PV systems, each using a 3 kW Xantrex grid-tied inverter, combine at the main AC service entrance.

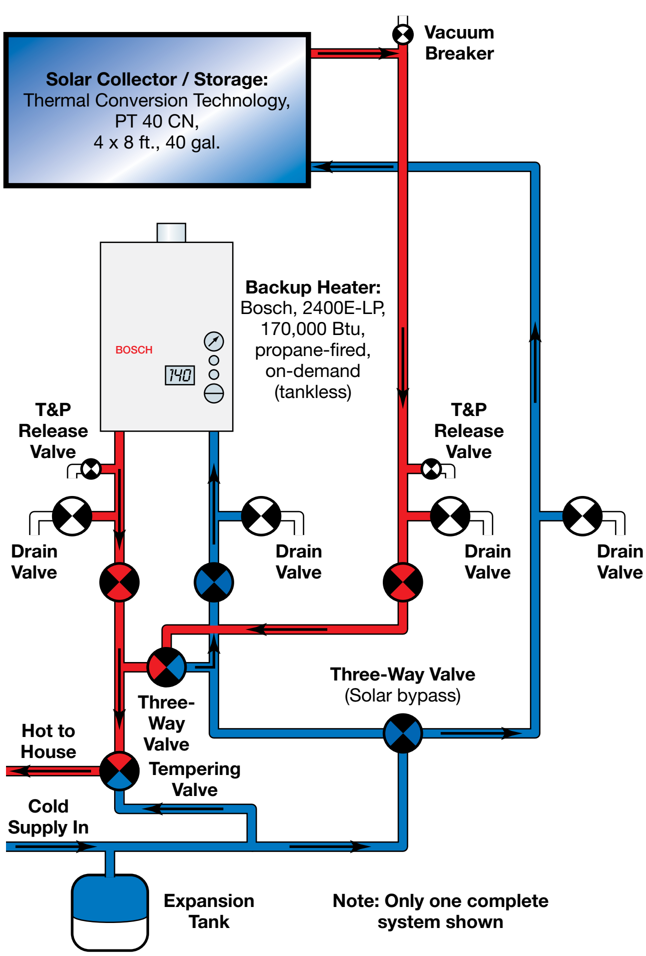
The meters here are, left to right, an auxiliary circuit used during construction and testing, the utility main meter for net metering, and the solar production meter for the utility.

Del Fierro Batteryless Grid-Tied PV System



Above left: At first glance, this collector looks like a typical flat-plate unit. However, this is a batch-type collector—a progressive-tube, integrated storage/collector. Two (only one shown) each hold 40 gallons of water, eliminating the need for a separate storage tank. (Note: These are only used in nonfreezing climates.) Above right: The system has only a few simple components beyond the collectors—an expansion tank and backup tankless heater.

Del Fierro SHW System



period, thermostats were set for 80°F in summer and 68°F in winter. The HVAC system measured 2,382 kWh over what was anticipated.

To evaluate the building's thermal performance, thermocouples were embedded in eight strategic locations one inch from the inner and outer surfaces of the exterior walls. Data was recorded on a computer every 15 minutes over a period of a year. This was helpful in understanding where heat transfer was significant so adjustments could be made. One zone with south and west exposure consumed power disproportionately—29% of the HVAC power used for 11% of the building floor space. Planting shade trees on

SHW Tech Specs

Overview

System type: Integrated storage tank system, 80 gal. total capacity

Solar resource: 6.5 average daily peak sun-hours

Production: Unknown

Percentage of hot water produced annually: 95% (estimated)

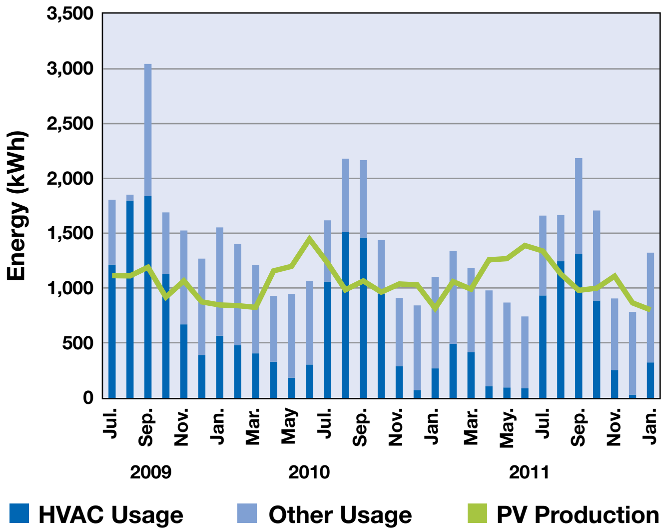
Equipment

Collectors: Two Thermal Conversion Technology PT 40 CN, 40 gal.

Collector installation: Roof-mounted; south-facing; 34° tilt

Backup DWH: Two Bosch 2400E-LP, propane-fired, tankless

Energy Production & Use



Deep roof overhangs provide ample shade for outdoor spaces.

those sides of the house largely corrected this problem. It was also found that the default settings on the heat pumps caused the variable-speed fan motors to operate all the time, which was unnecessary for comfort. Filters were changed more frequently and a fan was added to the cooling tower, and used in the spring and early summer months, providing needed humidity. Implementing these strategies reduced the zone to 19%.

About a cord of wood was burned in the fireplace during the coldest months, reducing the nighttime heating load. These changes had no effect on lifestyle and helped keep us under the winter HVAC budget by about 4%.

Additional thermal mass in the concrete floors and earthen clay wall finish helps mitigate temperature swings in interior spaces.

PV production was improved by fixing a tracker problem and replacing several defective PV modules. Three module failures affected three strings of modules. With two identical systems, it's easy to spot a problem. Trees were removed that had grown and shaded one of the arrays during the late-afternoon hours. We also cleaned the surface of the modules more frequently, resulting in improving PV production from 12,317 kWh annually to 13,307 kWh.

The SHW systems consist of two 40-gallon ICS batch units at each end of the house, backed up by Bosch propane on-demand units. The systems' performance can be measured by the backup fuel that hasn't been used. The 300-gallon underground propane tank was filled to 80% of capacity at move-in. It has never been refilled, and today it's just under 60% full. That means about 60 gallons of LPG was used in 32 months (or 1.9 gallons per month). This consumption also includes a frequently used gas grill, which I suspect accounts for most of the gas usage.

This put us within 2% of our objective of meeting 90% of our energy needs without any compromise in lifestyle. We could squeeze out the last bit by managing computer systems, entertainment systems, and the phantom loads.

Access

A UCLA physics graduate, **Edward A. Marue** designs off-grid power systems for remote communications and border security sites. He is also a principal in Solar Lava Development Company, specializing in advanced green design and construction.

BATTERY INSTALLATION & MAINTENANCE

Story & photos by Lena Wilensky

A good charging regimen, regular maintenance, battery-handling safety, and recordkeeping are the mainstays of managing a battery bank.

Whether you spend $200 or $20,000 on your batteries, without proper care they may be headed to the scrap yard sooner than you would like. Here are some expert tips on battery installation, charging, and maintenance to make sure your investment is long-lived.

Installation

Proper housing. Make sure your batteries are housed in a safe, easily accessible place. Most batteries require an enclosure that is lockable, sealed, insulated, and vented outdoors. Small details such as sloped covers (so things are not piled on the box), clear viewing windows (for easy inspection), and a removable side (for ease in replacing batteries) can make a big difference. See "Battery Box Design" (*HP141*) for more tips and tricks.

Batteries are dangerous (see "Safety!" sidebar), and they should not be accessible to anyone unaware of proper safety protocols. But we also want the batteries to be accessible when they need maintenance. Cell caps on flooded batteries, and terminals, should be easily reachable. Consider battery layout, as it is preferable not to lean over one battery to reach another—making access easy reduces the chance of accidental shorting.

A well-made, insulated, outdoor battery box.

Courtesy Lena Wilensky

Interconnections. Some industrial batteries come with bus bars for making intercell connections, but most battery banks need cables for series and parallel connections, as well as cables to connect to an inverter or DC load center. Battery cables should be large enough to handle their maximum continuous current, and be protected with fuses or circuit breakers rated for high amp-interrupt current. Cable size is determined from the inverter specs and/or DC loads that come off the battery bank. For residential-sized systems, 2/0 or 4/0 cable is common.

Using welding cable for batteries was once a common practice, as listed cable was not available and it is relatively inexpensive, flexible, and can handle lots of current. However, it is not designed for this application and is not listed by the *National Electrical Code* for use in battery systems. Flexible, UL-listed, *NEC*-approved battery cable is now readily available, and should be used for *all* battery wiring.

Keeping batteries healthy requires equal charging and discharging across all cells—differences in resistance within a battery bank can lead to premature failure. Poor lug crimps, loose terminal connections, unequal parallel cable lengths, and small wire gauge can all affect the equal treatment of cells.

Wiring. Electrons can follow numerous paths when entering or leaving a battery bank with multiple parallel strings, so it's critical to minimize the number of parallel connections and ensure they are equal in length. When wiring parallel strings, always make series connections first. Next, parallel the positive ends of the strings, and then connect the negatives. Inverter cables should be connected on opposite corners of the battery bank to keep electrical paths between strings as equal as possible.

www.xantrex.com

The Xantrex LinkPRO is a common amp-hour meter for monitoring battery state of charge in smaller systems.

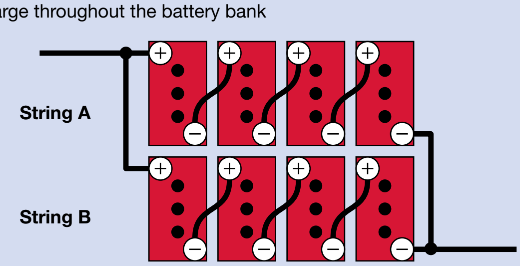
www.outbackpower.com (2)

OutBack's FLEXnet and Mate provide battery monitoring and a digital display for OutBack systems.

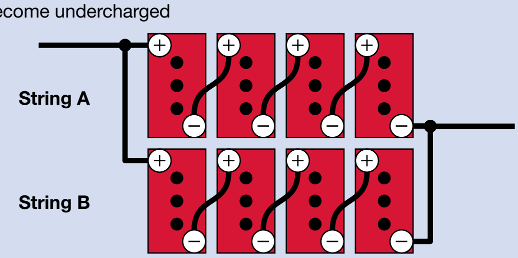
BATTERY WIRING

Four 6 V batteries are configured in two series strings to attain 24 V. Then the strings are paralleled to increase storage capacity.

Proper Wiring: Equal resistance for charge and discharge throughout the battery bank



Improper Wiring: String B will have more resistance (charge has to go through more cabling than String A) and can become undercharged



State of Charge

A battery's lifespan is affected by how deeply it is discharged before getting charged back up, and how long it stays in that discharged state. A battery's state of charge (SOC) is the amount of energy remaining in the battery. The lower the SOC is allowed to drop, the shorter its lifespan will be. Sizing an off-grid battery bank for 50% SOC is common, but remote systems with no backup power sources may be designed to maintain SOC at 75% or above to extend battery life—the fewer times a heavy, unwieldy battery bank needs to be replaced, the better. Backup power systems are often designed to go down to 20% SOC since they are rarely discharged.

Many methods use voltage to determine SOC, although it's not the most accurate measure. The voltage of a battery *at rest* can tell us SOC, but in an RE system, they are nearly always charging or discharging, so attaining this rested state is difficult.

The most accurate way to measure SOC on flooded batteries is by checking the electrolyte's specific gravity (SG). Hydrometers are the most common tool used to measure SG, but handheld refractometers can also be used. Be sure to choose one that is accurate to at least three decimal places, and follow the instructions for your model. The "SOC" table gives approximations, but the actual specific gravity and voltages will vary for battery makes and models.

SOC FOR GENERIC BATTERIES*

State of Charge	Specific Gravity	12 V Battery Flooded Voltage	12 V Battery Gel Voltage	12 V Battery AGM Voltage	24 V Battery Flooded Voltage	24 V Battery Gel Voltage	24 V Battery AGM Voltage	48 V Battery Flooded Voltage	48 V Battery Gel Voltage	48 V Battery AGM Voltage
100%	1.265–1.285	≥12.60	≥12.85	≥12.80	≥25.20	≥25.70	≥25.60	≥50.40	≥51.40	≥51.20
75%	1.215–1.235	12.40	12.65	12.60	24.80	25.30	25.20	49.60	50.60	50.40
50%	1.180–1.200	12.20	12.35	12.30	24.40	24.70	24.60	48.80	49.40	49.20
25%	1.155–1.165	12.00	12.00	12.00	24.00	24.00	24.00	48.00	48.00	48.00
0%	1.110–1.130	<11.80	<11.80	<11.80	<23.60	<23.60	<23.60	<47.20	<47.20	<47.20

*At rest, 77°F. Specific battery models will vary.

An amp-hour meter is a more common and fairly accurate way to keep track of SOC. These meters require a shunt to measure the current going into and coming out of the batteries, and some can keep track of more than one charging source (PV, wind, generator, etc.). Some have built-in alarms, generator start relays, and data logging capabilities. With proper setup, they can give you a much better picture of the SOC.

Charging Specs

Every battery has its own charging specifications. Chronic under- or overcharging is one of the most common ways to shorten the life of a battery bank. Undercharging can cause sulfate crystals to build up on the plates, reducing the battery's capacity and shortening its life. Overcharging leads to excessive gassing, lowered electrolyte levels (which cannot be replaced in sealed batteries), and more wear and tear on internal plates.

Generally, manufacturers give both voltage and current charging specifications. Check with the manufacturer for their recommended maximum charge rates. Most PV arrays are not large enough to supply that much current, so it is not usually an issue, but generator and utility charging can be. Sophisticated chargers have programmable maximum charge current.

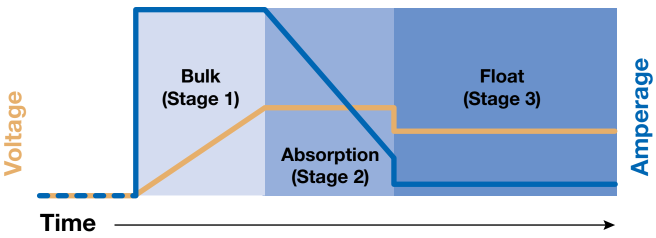
RE system batteries should be charged with a three-stage charger. During the first stage (bulk), all available charging current is sent into the batteries until they reach a specified voltage. Once they reach this voltage, they are about 80% charged, and the second stage (absorb) starts, and the current decreases just enough to keep the voltage stable. The absorb cycle has either a time and/or current end point (see "Absorption Time" sidebar). When this is met, the batteries should be full. The charger then enters the "float" stage with a slightly lower voltage and a trickle charge keeps the batteries full. Occasionally, the battery bank will need to be equalized to remove imbalances between batteries and cells. This is accomplished by intentionally overcharging the bank. See "Methods" in this issue for details.

Chargers

Reliable, programmable charge controllers will ensure batteries do not get overcharged, and a low-voltage disconnect (LVD) protects them from being overly discharged. Most residential inverters have a built-in, programmable LVD, but beware of smaller units with a set LVD. These often trigger at a very low voltage (down to 10.5 V), not to protect your batteries, but to protect the inverter. An inverter LVD can only protect the battery bank from AC loads, not any DC loads. For small systems, some PV charge controllers add

A hydrometer is used to check specific gravity—an accurate measure of determining state of charge.

THREE-STAGE CHARGING



TYPICAL CHARGING VOLTAGES*

	12 V Battery			24 V Battery			48 V Battery		
Charge	Flooded	Gel	AGM	Flooded	Gel	AGM	Flooded	Gel	AGM
Bulk, absorb	14.4–14.8	13.8–14.1	14.3–14.6	28.8–29.6	27.6–28.2	28.6–29.2	57.6–59.2	55.2–56.4	57.2–58.4
Float	13.2–13.5	13.4–13.7	13.4–13.7	26.4–27.0	26.8–27.4	26.8–27.4	52.8–54.0	53.6–54.8	53.6–54.8
Equalize	15.0–16.0	No!	No!	30.0–32.0	No!	No!	60.0–64.0	No!	No!

*Voltages will vary by manufacturer.

this function—for larger systems with DC loads, a dedicated controller may be needed for LVD.

Another common problem is a lack of adequate charging capacity. Batteries should be brought to 100% SOC at least once a week—and more often is better. Be sure your charging source can deliver enough energy to replace daily usage and to catch up after any periods of days without input. For example, if you've designed a battery-based PV system to have three days of autonomy, but your PV array only produces enough energy to replace 1 to 1.5 days of energy use, you'll need another charging source to "catch up" after three cloudy days or your batteries will spend too much time in a discharged state, shortening their life. This is one of the main reasons why many off-gridders have backup generators.

Temperature

Battery voltage is temperature-sensitive, and you'll need to ensure that batteries are not overcharged when they are hot

Measuring the voltage of your whole battery bank can give an idea of its SOC, but not of the performance of individual cells.

Courtesy Lena Wilensky (2)

ABSORPTION TIME

Ideally, there would be enough energy put back into the battery to bring it up to 100% SOC each day. Sounds simple, but loads and available charging vary almost constantly. An amp-hour meter can help, since it keeps track of the net energy in the batteries, but many charge controllers only have an absorb "time limit" function.

Manufacturers have a formula that can estimate this time limit based on expected SOC, available charging current, and battery capacity—but it is still just an estimate. Since PV systems often have relatively low charging current, erring on the longer side for PV charger absorption times is appropriate for most off-grid systems.

For example, Surrette Battery Co. provides the following formula:

Absorb time = (0.42 × battery's 20 hr. capacity) ÷ charge current

If there's 800 Ah capacity, and 75 A of charge current:

(0.42 × 800 Ah) ÷ 75 A = 4.5 hrs. absorb time

More sophisticated charge controllers also have a current trigger to end an absorb cycle. The higher the SOC, the less current is needed to keep the battery at absorb voltage. Since most PV charge controllers start a new bulk/absorb cycle each day, this is a great way to ensure batteries are getting just enough of a charge—even when they start at different SOCs. For example, a vacant off-grid cabin will not need much PV absorb time, since the batteries will be relatively full each morning. When the cabin is being used and the batteries are being discharged more deeply, PV absorption should be maximized.

SAFETY!

Filled with acid, emitting flammable hydrogen gas, and with exposed lead terminals capable of providing thousands of amps, batteries are dangerous. If short-circuited, they can explode. Caution should always be taken when working on or around batteries. Keep combustion sources away.

Wear protective equipment whenever the battery enclosure is open. Eye protection (goggles) and gloves (acid-resistant for flooded batteries) should be worn at all times, and an apron, arm covers, and face shield may be warranted as well. Wear long sleeves, long pants, and work boots, making sure that no bare skin is showing. In case there is any accidental contact with acid, it's much better to end up with a hole in your clothing than a burn on your skin!

Keep baking soda, distilled water, and paper towels or rags nearby to clean up any acid spill. A small emergency eyewash bottle is prudent as well. Always wash hands after working on batteries to remove acid as well as any lead that you may have inadvertently come into contact with.

A short circuit occurs if the positive and negative of a cell, battery, or battery bank become electrically connected. This can occur through the positive and any grounded metal parts as well. During a short circuit, large amounts of the energy stored in the battery are discharged in a fraction of a second. This can explode the battery or quickly melt the terminal and whatever was causing the short, and should be avoided at all costs.

Take these precautions to minimize the chance of a short circuit:

- Use insulated tools in and around an open battery box. A dropped metal wrench can easily touch both terminals. Remember to remove rings and watches as well.
- Before making battery interconnections, make a diagram that clearly shows each connection. Double-check it to avoid making a short-circuit connection by mistake.
- Cover all terminals except the two you are working on with clean, dry cardboard or rubber mats. Double-check intended connections against your diagram.
- Only have the tool you are actively using in your hand. Place ones you are not using at that moment away from the battery enclosure.
- Make sure there are no distractions. Other people on site should stay clear.
- Never disconnect a battery cable that is under load. Be sure to switch off/disconnect *all* power devices (inverter, DC loads, charge controllers) before attempting to remove or loosen any cabling. Remember that even with all devices turned off or disconnected, the batteries are still live.

Clockwise from top left: Distilled water, goggles, baking soda, chemical gloves, apron with insulated wrenches on top, hydrometer, and digital meter.

Use insulated wrenches for tightening connections to avoid accidental short circuits between the battery terminals.

Courtesy Lena Wilensky (3)

and not undercharged when they are cold. Most chargers have an optional remote temperature sensor that's placed in the middle of the battery bank (adhered to the side of a battery). Since a battery's temperature compensation requirement varies, always check manufacturer's specs and program your charger accordingly.

Regular Maintenance

Even if a battery bank is working well, performing routine maintenance can prevent future problems. All batteries should be thoroughly inspected at least once or twice annually. The cases and terminals should be kept clean and corrosion-free. While flooded batteries typically show corrosion buildup

Using a funnel to add distilled water to the batteries will help minimize spillage. Add a little at a time, pulling out the funnel periodically to check the level until the fill is just right.

around the terminals from gassing, it should be minimal. Sealed batteries should not have any buildup.

To neutralize any escaped acid, wipe battery cases and terminals with a clean cloth or soft brush dipped in a baking soda and water solution (1 pound of soda to 1 gallon of water), make sure vent caps are on and securely tightened. A bubbling solution is a sign that some acid is present; wait until bubbling stops and then wipe with clean water and dry. Be careful not to let *anything* into the battery through the vent caps.

Once the cases and terminals are clean, check the terminal connections and inspect the battery cables for any wear or loose crimps, and replace if necessary. Clean and recoat terminals and lugs with a thin layer of anticorrosion treatment (petroleum jelly works). Always leave your batteries clean so you can easily see any future corrosion or acid leakage.

Flooded batteries need to have their electrolyte levels checked every one to two months. Even if batteries only need to be filled every six months or so, checking water levels more often is recommended to ensure the plates are never exposed. If this happens, that part of the plate will quickly oxidize and block the chemical process there. Even if this only happens to one cell, it creates resistance and unequal charging throughout the battery bank and can reduce the whole system's efficiency and battery bank life.

Electrolyte should completely cover the plates, but be about $^{1}/_{4}$ inch below the cell fill tube. Overfilling is a common mistake. If you often find acid on your batteries, check that you aren't overfilling the cell. Shining a small flashlight into the cell can help you see the electrolyte level.

Only use distilled water for filling. Tap water, even filtered, can contain impurities that will harm your batteries. Use a funnel to help avoid spills. Hydrocaps and watering systems can help you keep batteries filled, but they are not a substitute for regular inspection. Also note that some of these devices need to be removed during equalization.

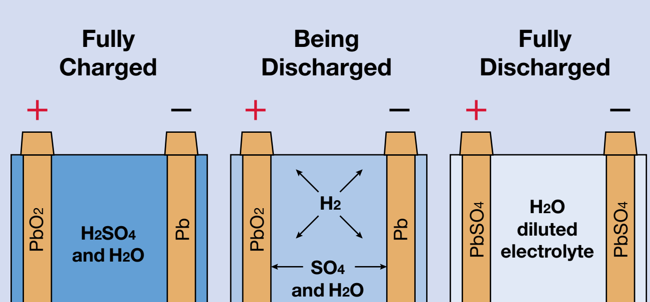
Signs of a Bad Battery

While an almost unlimited number of things can go wrong in a battery bank, there are a few signs and symptoms common in RE systems:

- The batteries complete a bulk/absorb charge cycle, but voltage plummets as soon as you stop charging and add a load, which indicates reduced capacity. Sulfate buildup has occurred and the batteries may be nearing the end of their life.
- One cell is different (voltage or SG readings; corrosion; appearance) from the rest often indicates that it is failing.
- Bulging cases are typically a sign of flooded batteries that have frozen. The frozen electrolyte expands and causes the cases to bulge, often forcing terminals and plates to warp, and cases to crack.
- Overheating or overcharging sealed batteries can cause cases to cave in. Excess pressure builds up inside the battery, and gasses escape through the safety valve covers. When the battery cools, some of the electrolyte is missing (from off-gassing) and the decreased pressure causes the cases to cave in significantly.
- Melted lugs/battery terminals could be the result of resistance from loose connections or corrosion buildup.

BATTERY CELL ANATOMY & CHEMISTRY

Lead-acid battery cells consist of lead and lead-oxide plates surrounded by an electrolyte, a mixture of sulfuric acid and water. Taking electricity out of the battery (discharging) causes the plates to change to lead sulfate, and dilutes the electrolyte. Putting electricity into the battery (charging) forces the sulfate coating off the plates and back into the electrolyte, making it more concentrated, and the plates return to lead and lead oxide. Hydrogen and oxygen gas are released during charging as some of the water molecules in the electrolyte break apart from electrolysis.



Recording

One of the best ways to track your batteries' health is to keep regular, precise records. During your maintenance checks, measure individual battery or cell voltages, and check specific gravity for flooded batteries. Ideally, readings should be taken after the batteries have been at rest for 12 to 24 hours and are fully charged, but this is generally impossible in an off-grid situation. Checking after 30 minutes of rest (no loads, no charging) will still give you good information.

These checks can alert you to bad cells, or let you know if the entire bank may be on its way out. Any differences in cell voltages or SG indicate you may have a failing (or failed) cell, and checking your readings against the expected SOC will tell you if they are losing capacity. The sooner you spot a problem, the more likely you will be able to fix it.

Check and record voltage readings for each battery so that you will notice if any are outside of the norm.

Courtesy Lena Wilensky

Access

Lena Wilensky (nunatakenergy@gmail.com) owns Nunatak Alternative Energy Solutions, a small RE design and installation company in the mountains of Colorado. She is a Solar Energy International instructor, a NABCEP-certified PV installer, and is certified by ISPQ as a PV Affiliated Master Trainer.

Further Reading:

"Managing Your Batteries" by Dan Fink in *HP142*

"Battery Box Design" by Allan Sindelar in *HP141*

"The Top 10 Battery Blunders—And How to Avoid Them" by Windy Dankoff in *HP114*

RE Battery Manufacturers:

Concorde Battery • www.concordebattery.com

Crown Battery • www.crownbattery.com

Deka/MK • www.dekabatteries.com

Discover Energy • www.discover-energy.com

Exide Technologies • www.exide.com

Fullriver Battery • www.fullriverdcbattery.com

Hawker • www.hawkerpowersource.com

Interstate Batteries • www.interstatebatteries.com

Solar-One/Enersys • www.hupsolarone.com

Surrette/Rolls Battery • www.surrette.com

Trojan Battery • www.trojanbatteryre.com

Universal Power Group (UPG) • www.upgi.com

U.S. Battery • www.usbattery.com

MidNite Solar

Our Techs Have the Experience

Off-grid systems are complicated, that's why we have the best technical support staff!

Ryan, with a degree in Electronics and being a licensed electrician for over 20 years, has specialized in off grid solar and wind installations.

Living in Maine, Ryan and his family use solar, wind and a reliable generator to power their off grid, self-built homestead. A 10ft Home Brew wind turbine and 3kw of solar panels provide all the power they need.

Ryan joined the MidNite team in 2010 as Technical Support Manager.

Ryan Stankevitz
Technical Support Manager

Tom Carpenter
Technical Sales Manager

Tom built his first working solar panel in 1972 using space grade cells which were left over from Sky Lab's solar wings. In 1980 Tom moved permanently off grid and started his own solar installation business.

Specializing in off grid system design and installation, Tom moved to Hawaii in 1992. He then became a partner in Outback Power Systems, doing beta testing and product development. In 2010 Tom joined MidNite Solar as Technical Sales Manager.

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The Electric Gardener

by Ted Dillard

NEW TOOLS FOR CLEAN & GREEN LAWN, FARM & GARDEN CARE

This Recharge G2 riding mower is quiet, electric, and emissions-free.

The change in season triggers familiar rituals for gardeners and farmers alike. As the days get longer and the ground gets warmer, it's time to plan gardens, order plants and seeds, and clean up the ravages of winter. And, it's time to perform maintenance on the gasoline-powered garden tools, whether it's mothballing the snow blower, tuning up the tiller and mower, or trying to start that stubborn chain saw.

It's a familiar routine, and preparing your tools can take a considerable amount of time. Then there are the parts, oil, filters, and gasoline that have to be changed, drained, and properly disposed of.

That's only the beginning of the gasoline tool problem. Small spills in a yard or farm are common enough to warrant mention in an Environmental Protection Agency (EPA) report, which says 17 million gallons of gasoline are spilled each year refueling lawn and garden equipment. (Just for comparison, the Exxon Valdez was estimated to have spilled between 10 and 30 million gallons of Alaskan crude into Prince William Sound.)

No effective emission controls exist for small gasoline engines, with the consequence that they are among the highest-polluting of gasoline power sources, even when

in good running condition. Several studies say that small gasoline engines account for 5% of U.S. air pollution. According to the EPA, just one gas lawn mower produces each year 88 pounds of carbon dioxide and 34 pounds of other pollutants. A gas mower produces eight times the pollutants as a new car driving 55 mph for the same amount of time, according to studies. Effects on climate change and plant life aside, you have to consider how much of this the tool operators are breathing.

Going Electric

Stricter standards will be in place for new equipment this year, but at best they aim to reduce emissions by about 30%. There's one way you can reduce them by 100% immediately—stop using them. Electric lawn and garden tools, besides being convenient and quiet, are a very responsible and attractive choice.

Corded electric tools are often thought to be limited to small hand tools, like hedge and walk trimmers, leaf blowers, and small snow blowers or light-duty lawn mowers. Battery-powered electric lawn tools, with old-style lead-acid batteries, were notoriously heavy and often underpowered. Until recently, heavier-duty electric tools for farm and garden—corded or battery powered—were not available.

Today, with lithium-ion batteries in the mainstream, a new generation of far more powerful and practical cordless lawn and garden tools has emerged. We're also seeing some truly professional-grade corded tools like wood chippers, firewood splitters, and snow blowers. Battery-powered lawn tractors and small utility vehicles (with speeds up to 30 mph) are also on the scene. And backyard mechanics are converting everything from rototillers to antique tractors (like the vintage Allis Chalmers G, which has a huge following for electric conversions) to electric motors.

Before You Buy

It's time to take a fresh look at electric tools as a serious addition to the farm and garden arsenal. We've put together some examples of what's available as the latest generation of tools—far from a complete list, but intended to give a good idea of what's the latest and greatest. There are also some things to keep in mind when considering your purchase.

Noise. An electric tool is significantly quieter than its gasoline-engine counterpart. But don't expect tools that have high-speed spinning parts, like blowers and mowers, to be whisper-quiet. Something like a chain saw, though, will be remarkably stealthy—what we like to call "Sunday-morning quiet" in our neighborhood. An electric snow blower or utility vehicle can literally be run at any hour without fear of disturbing neighbors or your own household.

Power Ratings. Comparing a gasoline engine's rated horsepower to an electric motor is difficult. A gasoline engine is rated by its peak horsepower, but an electric motor is rated as "constant" power—its power output is fairly even throughout its rpm range, and most electric motors are run near their top speed. It's so difficult to get a handle on the

Other Electric Options

The simple act of using electric or hand-powered mowers can put you on the cutting edge of a cleaner, greener lawn revolution. You'll save some money and energy (or even burn a little of your own!), and—with the quiet operation and zero emissions of these mowers—stay in your neighbors' good graces.

Corded mowers have a plug-to-extension-cord type of connection. You will need an extension cord (14 gauge or better) if the run is long. Most manufacturers recommend a maximum run of 100 feet, so you'll need to remember this limitation for your lawn size. You'll also need to change your mowing attack so you don't run over the cord.

Cordless mowers rely on a battery pack to run the mower. While there are no limits on where you cut, there are limits on run-time length. Although cordless mowers are usually designed with the most efficient motors to achieve the longest run times, the battery's charge only lasts so long. These mowers recharge by plugging them into a standard 120-volt AC receptacle. Typical charge time ranges from 12 to 16 hours. Because they have sealed gel-cell batteries, which do not need to stay level, they are especially good for mowing sloped lawns.

Even if you don't power your home with solar energy, switching from gas to an electric mower will help reduce both air and noise pollution. Besides costing cents to operate, you also avoid costly engine tune-ups and messy oil changes. Electric mowers are easy to maintain, and start with the push of button, putting an end to the tiresome task of yanking on a starter cord.

Courtesy Black and Decker

comparison that it's probably not a good idea to compare gasoline apples to electric oranges.

Manufacturers rate their products either by volts and amps or by watts. For example, most corded tools run on household voltage—120 VAC—and have a particular amp rating. When comparing similar products, a higher amp rating indicates that more power can be delivered to the task. For example, a heavy consumer-grade log splitter like a 16-ton horizontal unit will pull up to 18 amps, needing a 20 A circuit to operate. A smaller unit may be rated at 16 A or less.

With products like log splitters, pay attention to the amount of pressure they can deliver. For example, electric log splitters' force ratings range from 4 to 20 tons, which indicates how effective they are. This force can be used to compare them to their gasoline counterparts.

A motor rated in watts can be directly compared with one rated in amps simply by dividing the watts by the operating voltage. A 120 V motor that pulls 16 A can also be rated at 1,920 W. It works in reverse, too. For example, a 120 VAC, 4-ton splitter rated at 1,500 W will draw about 13 amps (1,500 ÷ 120 = 12.5).

Courtesy Ted Dillard

This chain saw from Oregon Power Tools is light, powerful, and gasoline-free.

This Ramsplitter firewood splitter gets the job done with no smelly, poisonous exhaust.


Courtesy Ramsplitter

Batteries. For cordless tools, battery technology has improved greatly in the last few years—the most revolutionary being lithium-ion technology. Li-ion batteries are safe, lightweight, and long-lasting. They are half the size and weight of comparable lead-acid batteries with the same capacity—at usually twice the price.

Golf carts, fork lifts, snow blowers, and other applications where weight is an advantage, or lawn mowers and other large tools with attractive pricing a high priority, will continue using lead-acid batteries. They're inexpensive, last long enough, are heavy, and can be recycled—just what you want on a tractor, for example.

Getting Your Motor Started

Log splitters are a great example of a tool in which more power is better, and an example of electric tools breaking into a true professional-grade performance bracket. Small splitters can't handle much more than what can be taken care of with a couple of good swings with a splitting maul. Any wood that won't succumb to that needs a professional-grade log splitter.

A good example of one is the 3 hp, 240 VAC Ramsplitter, really nothing more than a standard 20-ton hydraulic splitter with an electric motor instead of gasoline. (And it's a good example of the difference in horsepower ratings between electric and gasoline units discussed earlier. This 3 hp electric version would compare to a 6 hp, 200 cc gas engine splitter.) At 240 VAC, it's not something you can plug into standard household receptacles, but could plug into outlets in a commercial shop or facility with other high-powered tools.

There's no exhaust, so electric splitters can be run in a shed, barn, or garage that's fully enclosed (and even heated).

Ear protection is not needed. You can find a few gasoline-powered splitters for nearly 40% less than electric, but there are also several offered at comparable prices.

Chain saws are a particularly good use for electric power. Though corded saws are handy because they offer high power with unlimited use time, in a large yard or estate they may not be convenient. That's where lithium-ion batteries come in.

As an example, I tested the PowerNow 40 V MAX line of lithium-ion battery-powered chain saws by Oregon Power Tools. The saw runs a 14-inch bar and weighs 11 pounds. The battery pack lasts long enough to cut up to 250 two- to three-inch-diameter branches on a single charge, according to Oregon's literature.

I put the PowerNow to the test after a fairly violent storm took down a few branches as well as a 6-inch-diameter limb from a favorite maple tree. A 200-year-old oak tree in a neighbor's yard also needed cutting and it was the first thing I took the saw to task on.

The PowerNow stood up very well to the 3-foot-diameter tree. Cutting without the ear-splitting whine and stench of a gasoline-powered chain saw was a joy. I went through two battery packs and, as is typical with lithium-ion batteries, they show little slowing down when they lose charge. The saw simply stops when the battery is completely discharged.

The saw is probably too heavy for rope or climbing work, and is not "professional" grade, but it's perfect for occasional homeowner. Being able to simply grab the saw off the shelf, switch it on, and start cutting is almost unnerving. You don't hesitate to switch it off and put it down, since starting it again is effortless, unlike my old gasoline-powered saw.

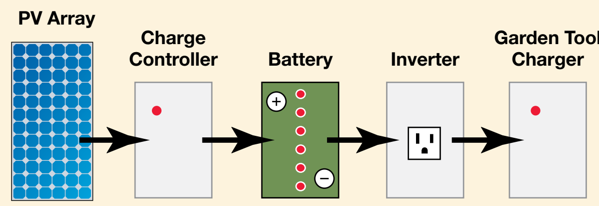
Solar Charging

Whether you are living off-grid; looking for a way to take advantage of solar power with a small investment; trying to avoid the oil and gas industries; or need to power your electric tools in a remote corner of your property, a small PV charging system can be right for you.

For a modest investment (usually less than $1,000), you can set up a small PV charging station. This is an especially good fit for the weekend-only tool user, so batteries can recharge over several days and be full for the next use. A small PV system on your garden shed can keep all of your tools ready without power lines and, once the system is paid for, no ongoing costs for electricity or gasoline.

Alternatively, if you have a household grid-tied PV system that offsets your utility usage, you can plug in your tools and charge from the sun, without setting up a dedicated system or dealing with batteries in the PV system.

Having a PV array charge a battery bank—which, in turn, powers an inverter to provide 120 VAC for plugging in a battery charger—is one approach to solar charging.



Are electric chain saws going to replace heavy-duty professional saws for cutting cords of wood every year? No, but they're great tools for someone with a few acres to keep cleaned up, or a tree or two a season to buck up.

Chippers come in to play after you're done with the saw. For a suburban yard and garden, a small electric chipper is just the ticket to mulch up twigs and leaves for the compost—but if you have branches, you need some power.

An impressive unit is the Patriot Products' CSV-2515, 1.5 hp, 120 VAC 14 A, electric chipper and leaf shredder. It can handle branches up to 2.5 inches in diameter. Though you don't have the engine noise, you're still going to get considerable noise from the spinning blades and their impact on the branches.

This is a tool used infrequently, but the benefits of electric are the lack of preparation and starting effort needed, and not having to deal with fueling and engine maintenance. You just run a heavy-duty cord to it (long lengths require larger wire) and switch it on.

Courtesy Patriot Products

This electric chipper from Patriot Products has the capabilities of a gasoline-powered chipper, but without the noise and emissions.

Courtesy John von Dorn

This AMP 24 Sno-Thro from Ariens can throw snow up to 40 feet.

Electric snow blowers are a tool for another season. The Ariens AMP 24 Sno-Thro is respectable by any standard: it has the ability to shoot snow more than 40 feet.

A perfect application of affordable, heavy (for traction) lead-acid battery power, the AMP 24 claims an operating time of 45 to 60 minutes. The retail price is around $1,700 (at the top end of the scale, but not higher than some premium gasoline-fueled models), and they can be purchased at home center stores.

Electric tractors are a field that is surprisingly vacant. One riding mower, with a 27-inch cutting deck and 3-hour run time before recharging, is available from Recharge Mower. It costs about 2.5 times as much as its gasoline competitors, but is virtually maintenance-free.

This is an area where we're seeing the DIYers converting lawn tractors and some folks offering complete conversion kits. Considering the now commonplace vehicles like golf carts and the affordability of lead-acid batteries, converting a lawn-tractor to electric seems pretty straightforward. Rather than a standard PTO (power takeoff) to run accessories, converters use another motor to drive the mower deck, tiller, or even a snow blower.

One company offers a kit for a remarkable, and unusual "host" tractor—the Allis Chalmers G model. With commercial batteries and a fork lift motor, a golf-cart controller system, and some fabricated mounts, you can take one of these vintage beauties and give it new, clean life.

The Niekamp Tool Company makes it easy, offering complete kits and tutorials for converting your own. The kit includes the bell-housing adapter plate, motor plate, stub shaft, and pulleys with bearings for $500. You can use lead-acid batteries, with weight that works in your favor, in the case of a tractor.

The Niekamp Tool Company makes a conversion kit for vintage Allis Chalmers G tractors.

Courtesy Niekamp Tool Co. (2)

The weight of the lead-acid batteries works in this tractor's favor by providing additional traction.

Like the electric vehicle market, the electric farm and garden tool market is starting to get a boost from advances in battery technology, increased awareness, and a booming interest in working and living with sustainable energy. Besides all that, though, electric farm and garden tools just make working and living on your land a whole lot more enjoyable.

Access

Ted Dillard (ted@evmc2.com) has been an avid gardener since childhood and is an evangelist for all things electric. He writes *The Electric Chronicles* (devoted to two-wheeled electric vehicles), and is the author of *...from Fossils to Flux*, a basic guide to building an electric motorcycle. When he's not in his garden or in his shop working on his next electric project, he can be found at www.evmc2.com.

Lawn & Garden (Small Gasoline) Equipment report • www.epa.gov/otaq/equip-ld.htm

Clean Air Gardening • www.cleanairgardening.com • Electric push & riding mowers

Driven by Solar • www.rechargemower.com • Recharge riding lawn mower

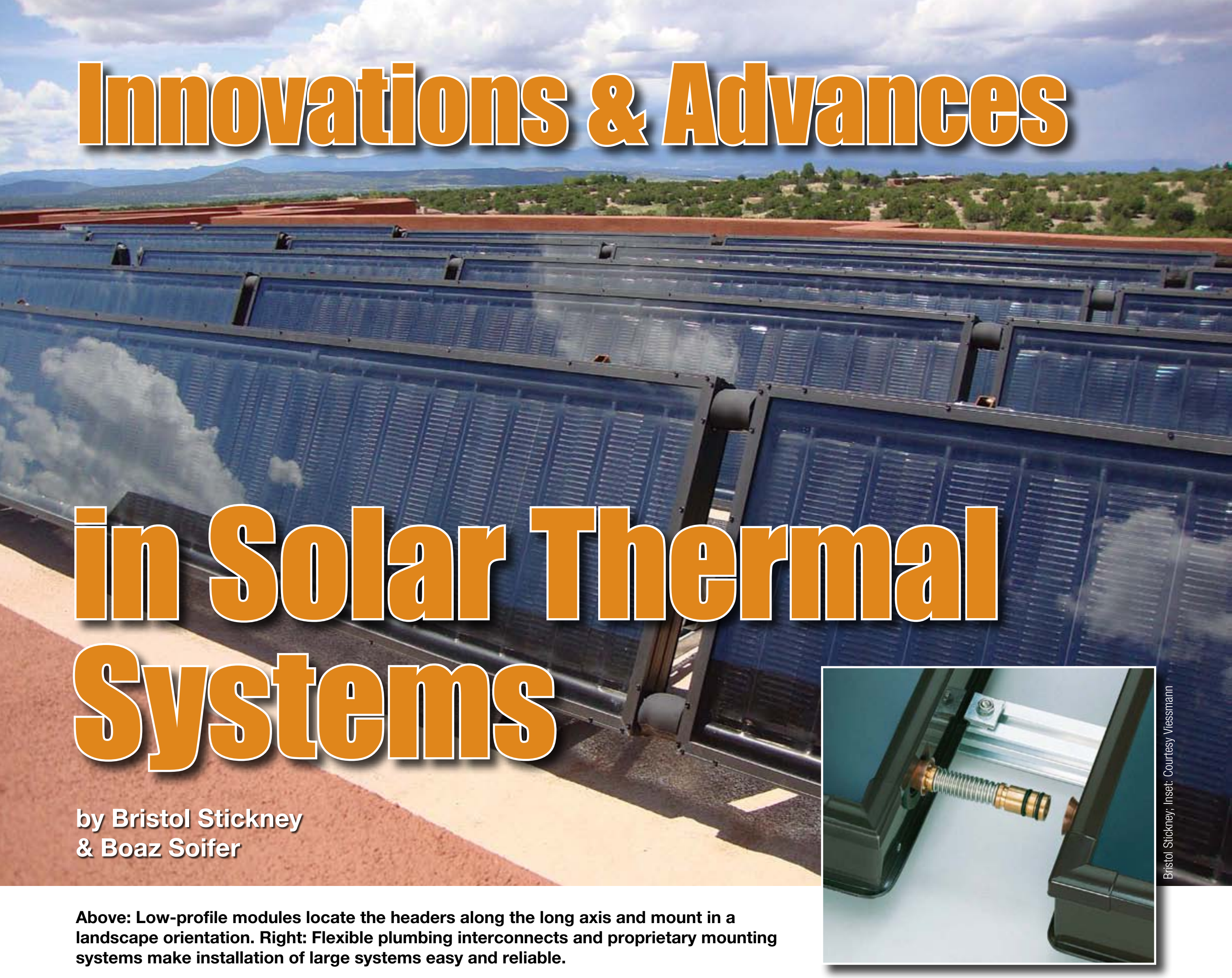
Logsplitters Direct • www.logsplittersdirect.com • Electric log splitters

Niekamp Tool Co. • www.niekampinc.com/electric-g-tractor/ • Conversion kit for Allis Chalmers G tractor

Patriot Products • www.patriot-products-inc.com • Electric chipper/shredder

Innovations & Advances in Solar Thermal Systems

by Bristol Stickney & Boaz Soifer



Bristol Stickney; Inset: Courtesy Viessmann

Above: Low-profile modules locate the headers along the long axis and mount in a landscape orientation. Right: Flexible plumbing interconnects and proprietary mounting systems make installation of large systems easy and reliable.

Changes in solar water heating have come in small increments. But when you add up all the recent minor innovations, you find that the world of SHW has changed significantly—mostly in serviceability, reliability, and installation ease. To get the industry's viewpoint, we spoke with veterans like Bob Rohr, chief trainer for Caleffi; Randy Hagen, president of Solar Skies; and other industry insiders.

Innovative installation practices go hand in hand with innovative products. This focus is mostly on "things that work"—components and practices that offer a track record of improved performance, longevity, or ease of installation.

Collectors

Flat-plate collector technology has not changed much. The best-performing black absorber plates are coated with selective surfaces, which maximize the collector's absorption of short-wave solar radiation, and covered with a layer of low-iron, high-transmission tempered glass. The frames and insulation will withstand severe weather and up to 350°F inside without failure. Collectors are tested and rated by the Solar Rating & Certification Corporation (SRCC). Although there are many sizes and brands to choose from, collectors with similar construction tend to perform similarly.

There are increasingly more companies offering evacuated-tube collectors, which can be considered in colder, cloudier climates or where higher water temperatures are required. Flat-plate collectors usually cost less (per square foot of collector area) and perform well throughout most of the country. Collector manufacturers offer accessories like mounting hardware, union connections, and other features that can make an installation faster.

With their smaller size, Solar Skies SS16 square collectors are easier to lift to the roof than larger rectangular collectors.

Bristol Stickney (2)

Concealed connections on low-profile collectors mean less visual clutter.

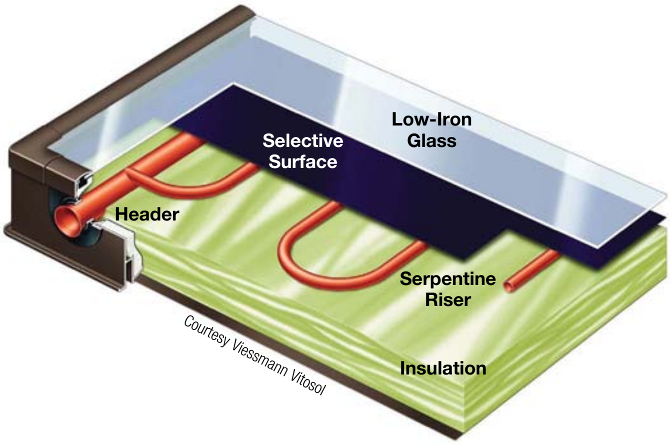
Low-profile collectors, which can fit more closely to the roof and have more concealed connective pipes and components, have less visual impact on the roof:

- Solar Skies SS16 is a square (4- by 4-foot) flat-plate collector with a selective absorber coating. These collectors contain internal horizontal headers and vertical risers so that they connect side by side without external headers. This flow pattern is compatible with both closed-loop glycol and drainback systems.

  Despite requiring more solar collectors, use of these smaller square collectors can reduce labor. Ladders and rigging can be reduced or eliminated due to the small size and lighter weight (60 pounds). They are factory fitted with threaded unions to make the connection between headers with wrenches rather than a soldering torch.

- The Heliodyne Gobi 404 is also a square collector that shares all the advantages of the Solar Skies SS16. It has a selective coating, includes O-ring threaded unions on the headers, and weighs 85 pounds.

Viessmann's Vitosol collector's two large-diameter headers, mounted horizontally, allow adjacent collectors to easily connect on either side.

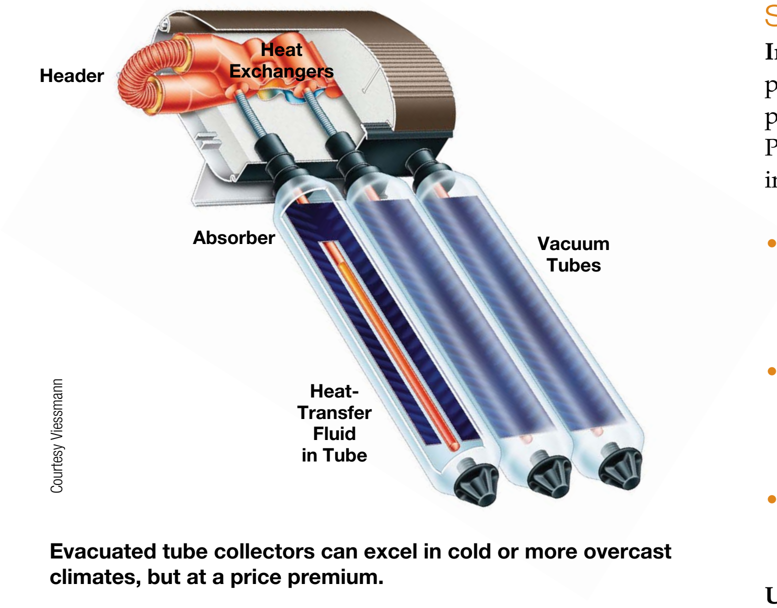


- The Viessmann Vitosol 100-F SH1B is a slightly larger low-profile collector. It has horizontal internal headers with a single serpentine riser tube. Because of the long, small-diameter tube, it is intended only for closed-loop glycol systems. The headers connect between collectors with a double O-ring plug using flexible stainless steel tubing instead of unions or couplers.

Drainback collectors. Caleffi's new drainback flat-plate collector, the StarMax V, drains via internal pitched piping. The tilted headers drain to the middle of the header and then to an outlet in the center of the collector enclosure. Multiple collector center ports can be connected together, even with piping hidden beneath the roof, to drain an entire array. They can be installed parallel to roof lines instead of at an east-to-west slant, and with hidden piping, making them less obtrusive.

Caleffi collectors designed specifically for drainback systems have sloped internal headers, negating the need for angled mounting.

Courtesy Bob "Hot Rod" Rohr/Caleffi



Courtesy Viessmann

Evacuated tube collectors can excel in cold or more overcast climates, but at a price premium.

Evacuated-tube collectors were the most radical design innovation for solar heating since selective surfaces were introduced in the early 1980s. Inside each glass tube, the black selective surface heat absorber is a long, narrow strip surrounded by a vacuum. The vacuum is an excellent insulator (much like a Thermos bottle) that makes the tube reach and retain higher temperatures more easily. A fluid within the absorber conveys the heat to a manifold, typically located at the top of the tube, where glycol or water delivers the heat to the solar tank.

The individual components—manifolds, tubes, and mounting system—are relatively small and can be carried up a ladder easily. Historically, the price of these collectors has been higher than flat-plate collectors of equal size, but recent prices have been declining.

Storage Tanks

In-tank heat exchangers. When storing solar-heated water, pressurized water tanks with internal heat exchangers have proven themselves long-lived, with low or no maintenance. Pressurized tanks successfully used in the United States include:

- Vaughn SEPCO SR "stone-lined" solar tanks available with a finned-tube coil and single- or double-wall heat exchanger;
- Heat Transfer Products SuperStor Contender tanks with one or two single-wall, stainless-steel heat exchanger coils;
- Triangle Tube Smart tank that uses a tank-in-a-tank, single-wall, stainless-steel heat exchanger design.

Unpressurized water storage tanks. There are also several options for unpressurized water storage tanks that are used typically with immersed heat exchanger coils, intended for drainback systems. These tanks are ventilated to the surrounding air through an open tube at the top to prevent pressure buildup in the tank.

- Solar Skies' Flexible Water Storage Tank, a collapsible atmospheric heat storage tank, is a new twist on the old idea of providing large water storage without using

With collapsible sides, this Solar Skies flexible solar storage tank can be easily maneuvered through doorways and other tight spaces.

Courtesy Solar Skies

Courtesy Viessmann

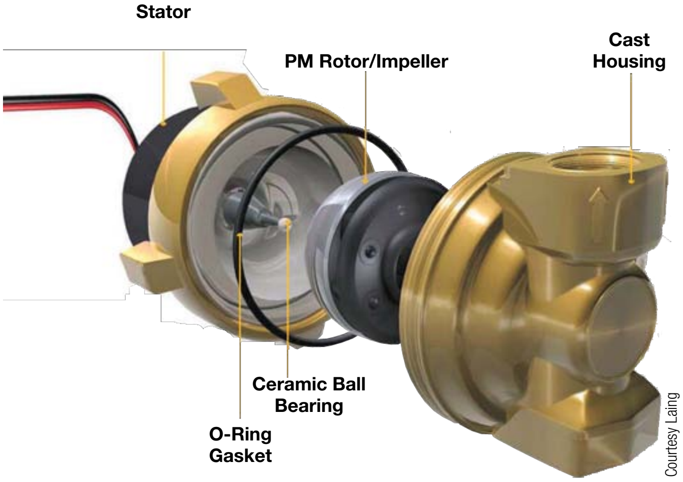
While conventional water heater tanks can still work for some SHW installations, today's solar storage tanks offer advanced features like multiple heat exchangers, excellent insulation, and backup heat options.

pressurized vessels. While this type of tank may require more maintenance compared with pressurized tanks, it has the advantages of having a much lower cost per gallon of storage capacity, easy transportability, and modular features. Besides being able to ship a tank with a very large volume in a very small package, collapsible tanks can come in handy in situations where a large tank is needed, but there's not enough room to get it through a doorway.

Multifunction storage tanks. Many pressurized storage tanks include electric heating elements and a thermostat, much like a conventional electric water heater tank. This is the easiest way to provide backup to your solar-heated water. The electric element is usually mounted near the top of the tank so that only the top is heated electrically, and the bottom remains cooler for better solar heat gain.

- The Vaughn tank and the HTP SuperStor have built-in electric backup. The Triangle Tube Smart Multi Energy tank offers the option of both an electric backup and a second heat exchanger coil for indirect heating with a boiler.

- HTP's Phoenix Solar Water Heater combines a high-efficiency boiler built into a stainless steel tank along with several heat exchangers. Solar heat can be delivered directly to the tank, and the 96% efficient burner can provide backup, rapid-recovery hot water.



Courtesy Laing

The Laing Ecocirc D5 pump has a permanent-magnet rotor/impeller that reduces the number of moving parts and seals.

Pumps & Pump Stations

Multispeed and variable-speed AC pump control. The solar heating industry has been packing more combined controls and features into its products. The heart of any active solar water heater is the circulator pump, which is becoming smarter and more efficient.

- The Taco "00" series has controls built into the electrical junction box on the pump motor. The OO-VS control can vary the pump speed in response to temperature changes measured by a thermistor wired to the control. The 00-VT control includes a differential thermostat using two sensors controlling the pump's start, stop, and speed. There are a number of other useful versions in this series of pumps and they all are programmable to tune the pump's performance to the job.

Taco's line of solar circulator pumps offers features like variable speed, soft start, integrated controllers, and drainback-specific models.

Courtesy Taco, Inc. (2)

Taco's X-Pump Block is a pump station with differential controller, two circulator pumps, and a built-in flat-plate heat exchanger.

Pump stations integrate the differential controller, circulation pumps, check valves, priming valves, safety valves, temperature and pressure gauges, and other basic components into a neat, easy-to-install, and well-insulated package.

Courtesy Bristol Stickney (3)

Solar pump stations. Solar domestic hot water systems in the United States have adopted the European-style enclosed solar pump station, which typically includes a circulating pump for the collectors, check valves, isolation valves, gauges, and are insulated with molded foam. Some include a differential control to activate the pump based on tank and collector temperatures.

- Many solar pump modules are designed for single-pump systems, such as the Caleffi 255 series, which can have an AC or PV DC circulator. Taco's X-Pump includes a flat-plate heat exchanger and two circulating pumps—one for the solar collectors and one for potable water.

- For combination space and domestic water heating systems, as opposed to solar domestic hot water systems, PAW, a German hydronic manufacturer, supplies modular piping systems that include "plug-together" manifolds and virtually all of the other heating system components. This makes a system easy to lay out and install. Pump modules are available with thermostatic mixing valves to control output temperature.

Some solar suppliers also package complete pre-engineered solar water heater kits with all of the necessary components, including the collectors, pump station, pipes, expansion tank, and glycol, taking the guesswork out of an installation.

Heat-Transfer Fluids

Propylene glycol & water. In drainback systems, water is usually the heat transfer fluid. During cold and sunless periods, the water drains out of the collectors to prevent freezing. For collectors that cannot be drained, the most common heat transfer fluid is propylene glycol (PG). It has a long track record and is widely available at a reasonable cost. This is not automotive antifreeze, which is ethylene glycol and is toxic—it should not be used in domestic solar heating equipment. Solar heat transfer fluid is usually a mixture of 50% to 60% water with less than 5% additives to improve its chemical stability.

Not all PG products are the same. The most important consideration is the manufacturer's high-limit temperature rating. Some products can operate normally up to 350°F. Solar collectors can exceed these temperatures during stagnation conditions, so the overheat prevention system must be designed with the PG temperature limit in mind. When in doubt, follow the recommendations of the solar equipment supplier.

- Solar glycol products include DowFrost, CryoTek, and Tyfocor.

- Glycol made from renewable resources has been in development. Bio-glycol, usually made from corn, is a high-quality product with superior heat transfer capability, potentially better price stability, and a high temperature tolerance. Dynalene, for example, has a high temperature rating of 350°F. Bio-glycol is also available from DuPont and other manufacturers.

Modern propylene glycol antifreeze is not only nontoxic, but also high-heat resistant. Some bio-glycols are made from corn.

Courtesy Viessmann

The differential controller is the brains of a solar thermal system, monitoring system temperatures and activating pumps.

Modern units are capable of handling complex systems and multiple scenarios, including overheating protection, diversion loads, nighttime radiant cooling, vacation modes, and multiple input and load monitoring.

Controls

Differential controls. A solar water heating or combination system's efficiency and provided comfort is only as good as its control system. The differential temperature (DT) control is the brain of an active solar water heater. The basic function of a DT controller is to measure two temperatures, turning the system on when one measures higher than the other. Modern DT units offer a low-limit setting to prevent operation until a minimum temperature is reached, and a high-limit setting to prevent overheating. Some include a vacation mode that allows heat shedding at night, and some have sensors and functions for energy measurement and additional control jobs.

- Basic AC-powered, single DT controllers for simple solar water heaters include IMC Instruments' Eagle 2, Steca TR0301U, Tekmar 156, and ReSol DeltaSol AL. For PV-powered DC solar heat control, the ArtTec DTC (1, AT, or D) and the Eagle D2 are available.

Data logging & monitoring. A trend in solar controls is toward more comprehensive systems, where one control box handles all the sensors and pumps.

- The latest models, such as the Steca TR 0603mc or the ReSol DeltaSol BX, have more of this capability but require expertise to program the control sequences that are right for each job.

Many controllers offer energy measurement or estimating that can be recorded and displayed.

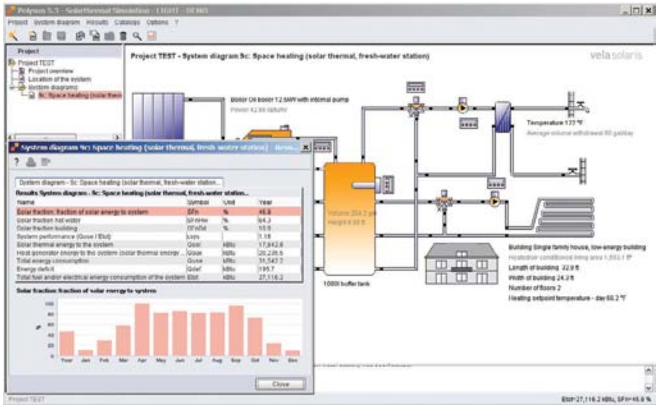
Btu measurement. In the future, we may see renewable energy credits (RECs) for solar heating. Solar heat can be metered to calculate a value for the fuel saved and carbon emissions avoided. If these RECs take off, accurate energy measurements will be important. Also, when solar heat is provided to a commercial tenant, the value of that solar heat may require metering, just like the other utilities.

Accurately measuring the heat flowing through a pipe requires continuous monitoring of two temperatures and the liquid flow. DT controllers have the capability of monitoring at least two temperatures, and the latest models include a flow sensor or a flow estimate capability to calculate Btu.

Flow metering. A flow meter coupled with temperature differential and two temperature gauges helps accurately measure the heat-transfer fluid's flow rate, making it easy to calculate how much energy your system is producing.

Courtesy Bristol Stickney

Some advanced controllers are capable of monitoring heat energy quantities based on temperature and flow with sensors like this Grundfos Vortex Flow Sensor.



Courtesy Vela Solaris

Vela Solaris's Polysun software assists in SHW system design, modeling, and performance predictions.

- Grundfos's Vortex Flow Sensor is a simple and robust flow meter. It has no moving parts, using a Venturi restriction with a solid state sensor to convert fluid motion into a flow signal. When combined with the temperature "In" and the temperature "Out" of any hot water control sensor, the Btu heat delivery can be calculated.

Memory cards & communication ports. Some solar controllers include removable memory cards and communications, offering users the ability to store and download data to their computers for more detailed system tracking and performance analysis. The displays, while still rudimentary, are becoming more graphical, animated, and user-friendly.

Multifunction SHW controls. Buderus, Caleffi, ReSol, Steca, and Tekmar all offer multifunction controls for more complex solar heating systems. The complexity of electrical connections and sophisticated computer logic escalates quickly in larger home-heating applications.

- ReSol's DeltaSol BX includes up to three differential thermostats, an adjustable thermostat control, and the capability to automate overheating protection. It can control up to four circulator pumps, has two variable speed outputs, connections for two kinds of flow meters, Btu monitoring, data logging, and five temperature sensors. This unit can control 26 pre-defined heating system configurations, making it exceptionally versatile.

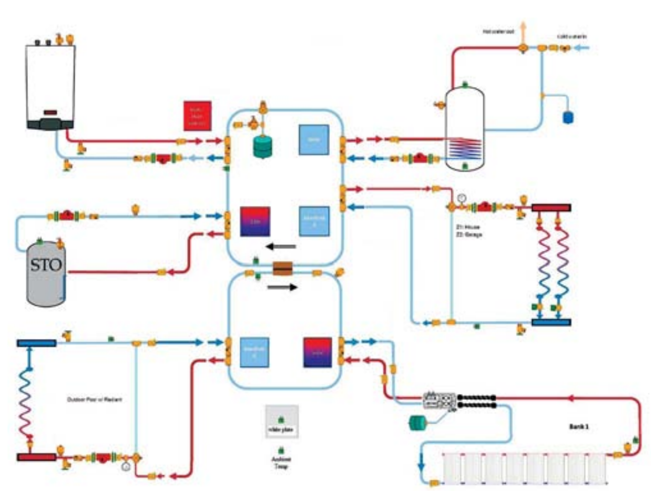
- SolarLogic's SLIC control takes a different approach to whole-home heating and combisystems, replacing all conventional controls with a single box with built-in software. All the pumps, sensors, thermostats and zone valves are wired directly to the single control. The SLIC can control solar and backup heat sources, 10 heating zones, domestic hot water, a heat storage tank, both a pool and spa, and an ice-melting system. It uses a vortex flow meter to calculate solar production, and monitors both glycol pressure and boiler water pressure. A pH meter monitors the glycol's condition. Built-in data logging keeps tabs on the heating system continuously.

Design & Analysis Software

When comparing solar heating system scenarios, computer design software uses weather data to simulate the performance of a variety of solar heating equipment. Three popular programs are Polysun, T*Sol, and RETscreen. All will assist the user in determining design for both simple and complex solar water heaters including: What is the monthly heating load? How much solar energy is available for collectors at a suitable tilt and orientation? How much solar heat is delivered and how much fuel is offset as a result? How do the costs and benefits compare to other design options?

- Polysun (from Vela Solaris) and T*Sol (from Valentin Software) can provide a graphical representation of the solar heating system configurations. This can help the

SolarLogic's SLASH-D software helps predict system output (left), models the system design (right), and ultimately becomes the programming for the SolarLogic SLIC integrated controller.



Courtesy Solar Logic (2)

Courtesy Bristol Stickney

With the integration of SHW components becoming more standardized, some companies are offering SHW kits.

designer visualize the system and get a handle on the parts list. These two programs are available with various features, ranging from less than $200 for the most basic to more than $1,500 for the professional versions.

- RETscreen was developed by Natural Resources Canada, and is free. It can evaluate energy production and savings, costs, emission reductions, and financial viability for various types of renewable energy and energy-efficient technologies (RETs). It is built into an Excel spreadsheet, and inputs vary with the project type. Solar collector and climate data for hundreds of locations in North America is included in the software. RETscreen does not provide the eye-popping graphics of the more expensive programs, but does provide some very useful analyses.

- SolarLogic's SLASH-D (SolarLogic Assisted Solar Heating Design) is solar design software that aids in designing a whole-house solar combisystem by using a standard piping configuration compatible with the SLIC control system. SLASH-D requires a minimum amount of information about the job, such as the size of the heated area, the number zones, and the size of the DHW hot water load.

The program then suggests the number of collectors and a recommended tilt and calculates monthly fuel savings. The program outputs piping diagrams of all primary and secondary plumbing and suggests a list of parts. Once the basic layout of the heating system has been determined, the output files from the SLASH-D become the input files for the SLIC controller so that it "knows" what components are in the system without further programming.

Access

Bristol Stickney has worked on all facets of solar heating systems for more than 30 years. He holds a bachelor of science degree in mechanical engineering and is a licensed mechanical contractor in New Mexico. He holds several solar heating and control patents. He is the chief technical officer for SolarLogic in Santa Fe, where he develops solar heating control systems and design tools.

Boaz Soifer is a founder of SolarLogic and has been involved in contracting and distributing hundreds of solar heating systems since 1999. He is currently also the vice president of sales at Focused Energy, a national wholesale distributor of components for grid-tied PV systems.

Featured Products:

ArtTec • www.arttec.net • Differential controller

Buderus • www.buderus.us • Solar controls

Caleffi • www.caleffi.us • StarMax V drainback flat-plate collector; 225 series pump station; iSolar solar control

Dow Chemical Co. • www.dow.com • DowFrost PG

DuPont • www.dupont.com • Bio-glycol PG

Dynalene • www.dynalene.com • Dynalene BioGlycol PG

Grundfos • www.grundfos.com • Vortex Flow Sensor

Heat Transfer Products • www.htproducts.com • SuperStor Contender solar storage tank with built-in heat exchanger; Phoenix Solar Water Heater

Heliodyne • www.heliodyne.com • Gobi 404 square flat-plate collector

IMC Instruments • www.solar.imcinstruments.com • Eagle 2 & D2 differential controllers

Oatey Co. • www.oatey.com • CryoTek PG

PAW • www.paw.eu • Pipe manifolds

ReSol • www.resol.de • DeltaSol AL differential controller; DeltaSol BX control; other solar controls

RETscreen • www.retscreen.net • RETscreen solar heating design software

SolarLogic • www.solarlogicllc.com • SLIC solar control; SLASH-D solar heating design software

Solar Skies • www.solarskies.com • SS16 square flat-plate collector; Flexible Water Storage Tank

Steca • www.stecasolar.com • TR0301U differential controller; other solar controls

Taco Inc. • www.taco-hvac.com • "00" series circulator pump; X-Pump pump station

Tekmar • www.tekmarcontrols.com • 156 differential controller; solar control

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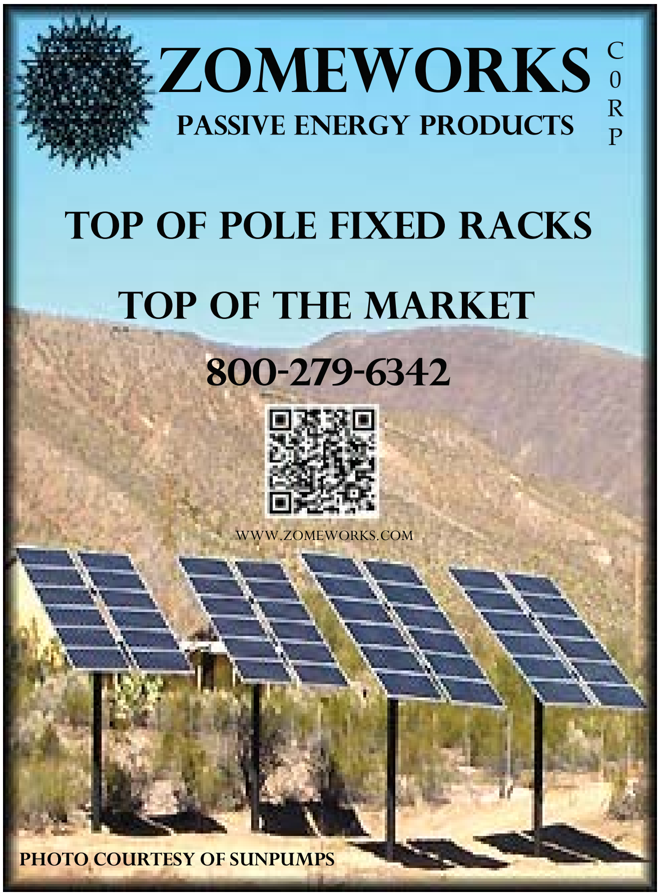
Viessmann • www.viessmann.com • Vitosol 100-F SH1B low-profile collector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Solar-Powered BIODIESEL

This facility in Colorado uses a solar thermal system to heat canola oil for biodiesel, which is used in the county's road-maintenance machinery.

by Laura Mezoff Christy
photos by Laura Mezoff Christy & Luke Christy

The remote and tiny enclave of Mesita, at the southern edge of Colorado's San Luis Valley, is not the sort of place where you'd expect to find a pioneering renewable energy facility. But at the edge of this isolated outpost sits Costilla County Biodiesel (CCBD), producing biodiesel from local crops—while part of the plant's energy is produced with sunshine.

CCBD is unique not only because of its remote location, but also because it is one of the few medium-scale biodiesel production facilities in the country. In 2010, my company, Solar Gain Services (SGS), designed and installed a solar thermal system to help the plant reduce its reliance on utility electricity—thus using renewable energy to power the production of a renewable fuel.

Raising Renewables

CCBD was conceived in 2001 by County Commissioner Joe Gallegos, who was looking for ways to create local economic development. Gallegos recognized that he needed to build upon the only strong private industry in the county: agriculture. He searched for a way to add value to local crops, and also studied whether this could be combined with the burgeoning growth of the RE industry. A feasibility study brought the idea of a biodiesel plant to the forefront—the county government consumes roughly 100,000 gallons of diesel annually to maintain its nearly 3,500 miles of roads. Though canola wasn't being grown locally at the time, a study showed that the crop was ideally suited to southern Colorado's climate, and was similar to seed crops that farmers were already accustomed to growing. Additionally, Gallegos discovered that the biodiesel process would churn out a nutritious by-product that could be sold to local ranchers for livestock feed.

In 2004, Project Manager Ben Doon procured a $150,000 USDA Rural Development grant to purchase equipment. Costilla County erected the building, and production began in 2006 with basic equipment.

"It was definitely *not* a turnkey facility," says Doon. "A lot of our small-scale production equipment was gathered from around the globe, where similar facilities exist. The equipment was procured piecemeal, and we had to figure out how it worked, often making modifications. Slowly, we tied all the equipment together to create a semi-automated production line. But in the beginning, everything was run by

hand. Materials were moved through the line using 5-gallon buckets and hand pumps. Now, seed is transferred with augers and liquid is pumped through pipes."

Since those early days, production has grown slowly but steadily. Today, CCBD makes roughly 50,000 gallons of biodiesel per year—about half the annual output that Doon would like to see in the next several years.

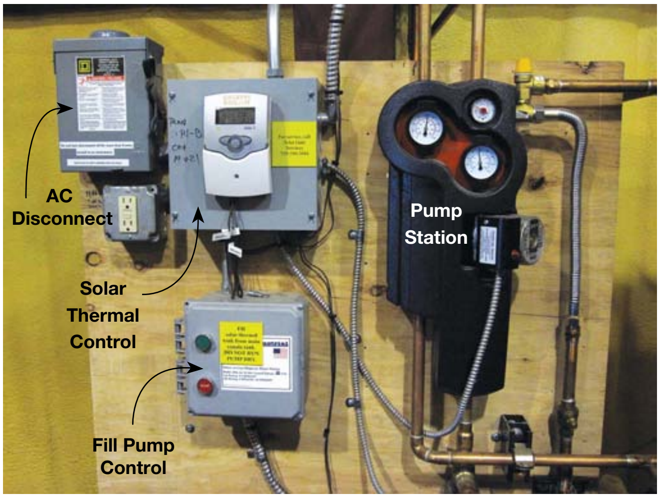
Renewables Powering Renewables

Since Costilla County has no natural gas pipelines, all of the facility's energy comes from electricity. With more than 300 days of sunshine and clear air, the San Luis Valley has one of the best solar resources in the country. As the plant's production increased and kinks were worked out, Doon thought about how solar energy could be used to decrease production costs while reducing the facility's carbon footprint.

He wondered whether solar could be used to heat canola oil to about 185°F to make biodiesel. Each 100-gallon batch was heated using electricity, from starting temperatures as low as 50°F. This consumed a lot of electrical energy, and also took nearly an hour, creating a production bottleneck. Doon asked SGS to design a solar thermal system and draft a proposal for grant funding. The grant was approved, and was received from the Governor's Energy Office of Colorado in 2010.

The solar thermal system uses nine roof-mounted Sun Earth EC-32 flat-plate collectors and a copper-coil heat exchanger inside a custom, insulated 400-gallon tank. The solar collector loop uses propylene glycol to prevent freezing during winter, while flow is controlled with a Viessmann pump station and a Caleffi iSolar 3 controller.

Room-temperature canola oil is pumped from a 1,500-gallon storage tank into the heat-exchanger tank. The oil is then heated by the solar-heated glycol solution running through the heat exchanger. To make a batch of biodiesel, 100 gallons of heated oil are drawn off the top of the exchanger tank using a metered pump. If the oil isn't warm enough, it is routed to a third, 100-gallon receiving tank, where an electric element can add heat. Usually, the solar-heated oil is warm



The control panel for the solar thermal system.

Unfiltered biodiesel tank (below left), solar control panel (far upper left), and canola oil tank (below right) viewed from above. The 400-gallon solar heat exchanger tank (center) has 3 inches of foam insulation and a galvanized sheet metal cover.

A copper coil heat exchanger inside the heat exchanger tank, which is partially filled with canola oil. The float switch sits in the tank's upper left corner, and a temperature probe is located in the center on the left side.

The seed sorter/cleaner removes chaff and other debris from the seeds before they are fed to the seed crusher.

Seed goes into the top of the seed crusher where it is crushed. The feed meal by-product is dumped into a bucket, and canola oil comes out of a chute on the left.

enough to be pumped directly to the reactor chamber, where it is mixed with methanol and sodium methylate to create biodiesel.

Hurdles & Accomplishments

Because vegetable oil is less dense than water, the size of the collector bank was adjusted accordingly. The specific heat of canola oil is lower than that of water, so fewer collectors are needed to heat oil. Although the glycol collector loop used standard equipment, materials and pumps that were compatible with vegetable oil had to be used in the oil loop piping. Because the heat exchanger tank is holding oil, rather than rust-inducing water, it was fabricated from cheaper mild steel instead of stainless steel.

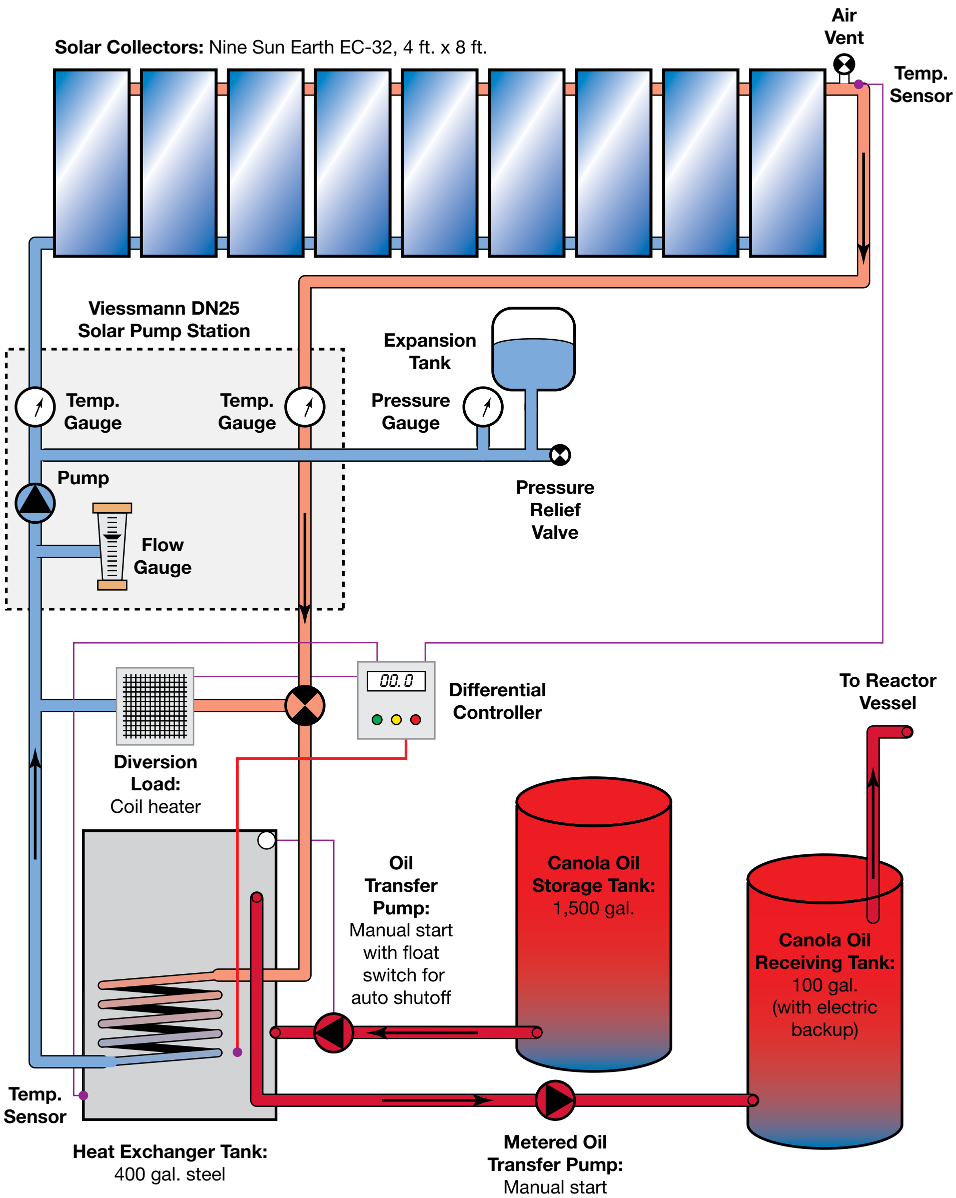
Feed meal coming out of the seed crusher. This is the by-product that is sold to farmers as nutritious livestock feed.

The unpressurized heat exchanger tank posed a challenge of how to refill the tank quickly with a minimum of manual controls. Accidentally overflowing the tank was a potential problem, so a float switch, which senses oil level and controls the fill pump, was installed. The lighter oil necessitated some experimentation, and required an oversized float and an oversized fill pump.

Canola oil has a much higher boiling point than water, so overheating is much less of a concern than it would be for a conventional water-heating system. Because hotter oil speeds up the chemical reaction, exceeding 185°F isn't a problem. This gives the system a lot of flexibility for when the hot oil can be drawn out of the exchanger tank.

The system still needs overheating safeguards for when the plant is not operating, to protect the collector loop and avoid breakdown of the glycol. When the collector loop reaches the high-limit temperature setting, the iSolar3 controller operates a valve to divert hot glycol to a fan/coil heater, which provides some limited space heating for the building. With moderate

SOLAR THERMAL SYSTEM



TECH SPECS

Overview

System type: Antifreeze (pressurized propylene glycol) solar thermal

Location: Mesita, Colorado

Solar resource: 6.0 average daily peak sun-hours

Production: 6.6 MBtu per month (average)

Percentage of canola oil heating provided: 100%

Equipment

Collectors: Nine Sun Earth EC-32 collectors, 4 x 8 ft.

Collector installation: South-facing, roof mounted, 45° tilt

Heat transfer fluid: Propylene glycol

Pump station: Viessmann, Solar Divicon DN25

Controller: Caleffi, iSolar 3

Storage

Tank: Custom steel tank, 400 gal.

Heat exchanger: 200 ft. of 1 in. copper coil, inside tank

System performance metering

Thermometer, flow meter & pressure gauges are incorporated into pump station

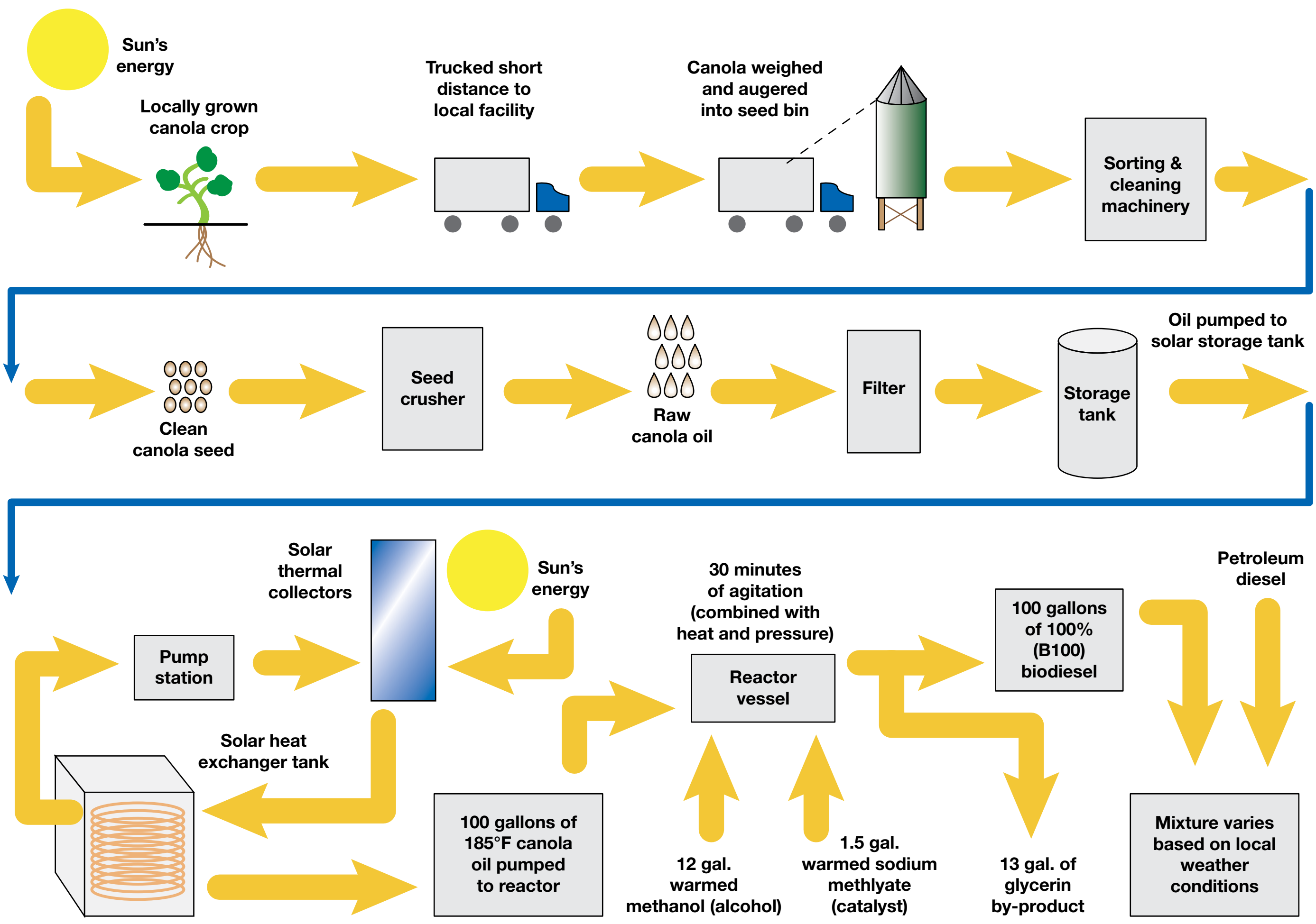
ambient summer temperatures, overheating of the large well-ventilated building was not a concern.

Function & Performance

The system has functioned well, providing the facility with a constant supply of solar-heated oil and considerably speeding up production. When sizing the system, we considered both the present and future needs of the facility. The goal of making approximately 100,000 gallons of biodiesel per year suggested a need for the system to heat 400 gallons of canola oil per working day. From there, we developed a system design and specified the collector array's size. The system's nine solar thermal collectors are capable of heating 200 gallons of water per day (on average) to the target temperature of 185°F. The specific heat of canola oil is about 45% of the specific heat of water and, as such, it takes less energy to raise the temperature of oil compared to water.

The facility's current production is close to 200 gallons per day. Excess heat produced by the collectors is used to heat the oil beyond its target temperature and to supplement space heating for the building. Since canola oil has high heat tolerance, and the system has safeguards to protect it from overheating, we were able to size the system for anticipated future production levels.

SOLAR THERMAL BIODIESEL FLOW CHART



Project manager Ben Doon stands next to a filter that removes impurities from the raw canola oil.

The system provides 100% of the current heating of canola oil, and will continue to do so until production increases require more than 400 gallons of oil per day. When they get up to 400 gallons per day, better scheduling will be required to heat as much oil as possible with solar.

Doon hopes to have a grid-tied PV system installed at the plant to offset some or all of the plant's electrical loads. Other solar thermal applications have also been discussed, but as of yet, there are no definite plans. Doon would like add a solar thermal project to heat the glycerin by-product enough to liquefy it, so that it can be burned in the plant's waste oil heaters that provide the space heating for the building. Currently, the facility does not have a good market for the glycerin by-product, so Doon would like to find a way to use the product as an energy source.

The CCBD has funded its production equipment largely through about $600,000 in grant money, but the project has had a larger effect within the community. Gallegos' original vision was one of local economic development, and the plant has created a new market for local farmers. It has created long-term jobs, and products that are made and sold locally. Farmers can buy the by-product feed meal, and

Exterior view of the CCBD plant. The grey tank contains methanol for making biodiesel. The smaller green tank contains petroleum diesel. Mixed (finished) biodiesel is stored in the larger green tank, where it is dispensed directly to the county's fleet of vehicles. The solar thermal collectors can be seen on the roof. The large bin on the right stores raw canola seed.

their dollars stay in the community rather than being sent off to non-local feed companies. And making their fuel locally means even more money stays out of the hands of the oil companies, and instead is being pumped back into the local economy.

The addition of a solar thermal system takes another step toward keeping local money close to home. CCBD has shown that even a small rural community can create something with a lasting impact through the power of renewable energy.

Access

Laura Mezoff Christy is the vice president of Solar Gain Services (www.sgsrenewables.com), a solar installation and consulting company that focuses on specialized solar thermal and PV systems. She holds master's degrees in architecture and city and regional planning from U.C. Berkeley.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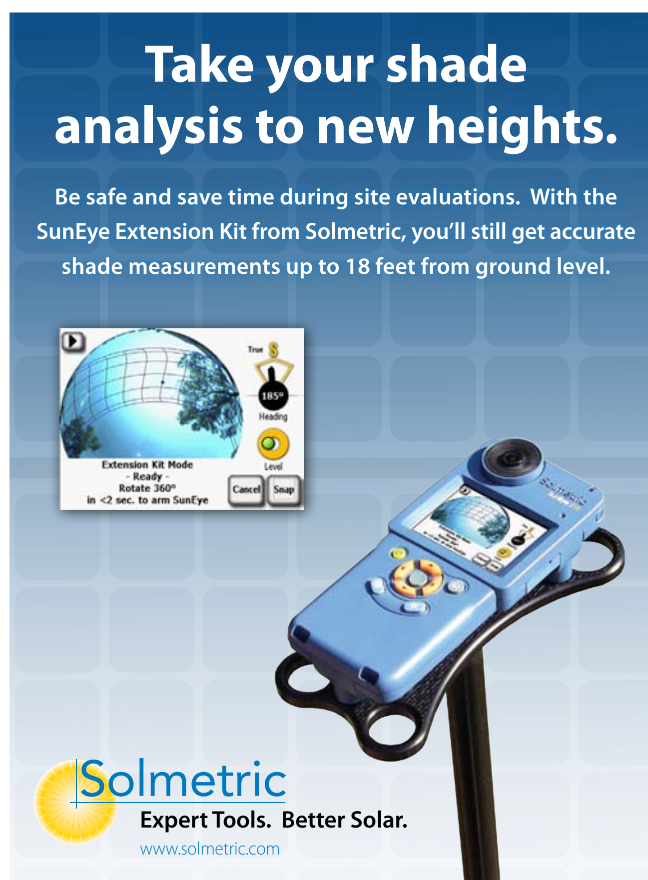
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Fuse Servicing & Disconnect Location

Story & photos by Brian Mehalic

The relative lack and expense of 600 VDC circuit breakers for PV systems means that fuses are commonly used for overcurrent protection in the ungrounded conductors of DC circuits. Section 240.15 of the *National Electrical Code* (*NEC*) requires overcurrent protection devices (OCPDs) for all ungrounded conductors, and Section 240.21 specifies that they be located "at the point where the conductors receive their supply."

Section 690.9(E) states that a single OCPD can protect an entire PV source circuit, meaning that fuses are not required between each module in series. OCPDs for PV source circuits are not located where the ungrounded "home run" conductor is connected to the last module because [per the exception to 690.9(A)], when the conductors and OCPDs are correctly sized per *NEC* Section 690.8(B), the current-limited nature of PV modules means that there is not a source of fault current that could damage the conductors or the modules.

However, once *multiple* PV source circuits are connected in parallel, there is a source of fault current that could exceed the rating of the individual home run conductors (as well as the interconnects between modules in series and the internal wiring of the modules themselves). Thus, the OCPDs are located where the potential supply of fault current comes from—at the point of parallel connection. Typical locations for these fuses are in combiner boxes where multiple series strings are paralleled or in grid-tied inverters with integrated series fusing.

Section 690.16: Fuses

Section 690.16(A) requires that a disconnect be provided for fuses that are energized from both sides, which is the case for fuses protecting paralleled source circuits—one side of the fuse is energized by the PV source circuit it is connected in series with, and the other side by the fuses it is connected in parallel with. Each fuse must be able to be disconnected independently of any other fuse.

In the 2008 *NEC*, Section 690.16(A) only required a disconnect if the fuses were accessible by unqualified persons. This loophole often resulted in a lack of disconnecting means—system designers assumed that only qualified personnel would be servicing the fuses.

However, fuses in PV source circuits are typically installed in non-load-break-rated holders (and they must be labeled as such per Section (690.16(B)). Opening them under load is not permitted, as this can result in arcing and fire. This is also the case with the touch-safe fuse holders typically used in smaller inverters with integrated series fusing. And in larger inverters, where fuses in re-/sub-combiners are typically bolted onto a common busbar, there is no way to safely service them without disconnecting power to all the fuses they are in parallel with, since they are energized on one side by the PV output circuit and on the other side by all the other PV output circuits they are in parallel with.

Section 690.16(B) is an addition to the 2011 *NEC*, and requires a disconnect on PV output circuits where fuses cannot be isolated from energized circuits. A disconnect has

Numerous manufacturers make combiner boxes with disconnect switches rated to break loads (the handle on the front of the box).

to be within sight (defined in Article 100 as "visible and not more than 50 feet distant") of any serviceable fuses, or be integrated into the fuse holder. If the disconnect is more than 6 feet from the fuse (but still within sight of it as required), then a directory that states the location of each disconnect must be placed where the overcurrent device is located. This section also states that the disconnecting means must comply with Section 690.17, requiring a manually operable switch—a non-load-break-rated fuse holder alone will not suffice. Note that for systems with a single combiner box, or inverter integrated series fusing, shutting down the inverter, thus removing the load, is an option for fuse servicing, particularly if the series fusing is inside the inverter, or the inverter is "within sight of" an external combiner box. With the flow of current removed, non-load-break-rated fuse holders can be opened to service the fuses they contain.

These two *NEC* sections indicate that load-break-rated disconnects should be installed on the output of, and within sight of, PV source circuit combiners; and, on the source side, within sight of re-/sub-combiners in a PV system. Not only does this make it safer and easier for service, these disconnects also allow emergency personnel to isolate or segment a PV array in the event of fire.

While the intent and interpretation of Section 690.16 can be debated, there is no doubt that many existing systems have too few disconnects, making it difficult to safely service fuses. System designers have often relied on inverter-integrated DC disconnects in larger systems with multiple combiner boxes, but these do not isolate individual DC input circuits from each other. They disconnect the entire, paralleled DC circuit from the inverter itself, leaving the fuses still energized on both sides.

In larger, central inverters, fuses on PV output circuits are typically bolted to a busbar, making it impossible to safely service them without a disconnecting means.

Many residential string inverters are available with integrated disconnects and series fusing.

Design Considerations

Although there are many variations in PV system sizes and layouts, there are two locations to consider for placing disconnects—at the PV output circuits originating from combiner boxes, and at the DC input to grid-tied inverters.

On systems with a single combiner box that contains fuses in holders, the inverter switch can be used to shut off the system, thus stopping the flow of current. Once this has been verified with a clamp-on ammeter, non-load-break-rated fuse holders can be opened to service the fuses inside. If a system consists of a single roof-mounted combiner box (not "within sight of" the inverter), then a disconnect (either integrated into the combiner box or a separate, external switch) can be used to open the load to service the fuses via their touch-safe holders. In these cases, running the individual PV source circuits all the way to the inverter is the best practice—an additional external disconnect won't be required if it's included with the inverter; the fuses will be easier to service if they are at ground level; and the fuses won't be exposed to higher temperatures on rooftops.

As system size increases, so does the likelihood of having multiple combiner boxes. Again, the disconnect on the PV output circuit from the combiner box—either integrated into the combiner box or as a separate, external switch—allows the power to be disconnected so that fuse holders can safely be opened. The disconnects also allow the combiner box to be isolated from the others it is paralleled with, so that the entire system does not have to be shut down.

If all combiner box disconnects are within sight of the inverter, then they can function as the disconnects for the fuses in the inverter re-/sub-combiner. However, in larger inverters with bolted-on fuses, this is unlikely, thus disconnects for each fuse will be required at the inverter. Since the fuses are in parallel, the only way to remove power from both sides of any one of them is to remove power from all of them.

These 600 VDC rated switches are used to disconnect power and isolate fuses for service in a large, central inverter.

This large disconnect switch (to the right of the inverter) is used to turn off power to all of the PV output circuits in the inverter.

What the Future May Hold

With larger systems, 600 VDC rated circuit breakers may become more common and less expensive. Some central inverter manufacturers are already switching to breakers (or offering them as an option). Using breakers instead of fuses for PV source-circuit overcurrent protection would remove the need for a separate disconnect, as fuse servicing is moot; unfortunately, this is currently an expensive proposition.

The 2014 cycle of the *NEC* will likely hold many changes, possibly adding a definition of combiner boxes, and better clarifying where and when disconnects are required. System designers should be proactive, and instead of trying to minimize the number of disconnects in an attempt to further lower the installed cost, work to ensure that PV systems are safe to service for the many decades that they will be in operation.

Access

Brian Mehalic (brian@solarenergy.org) is a NABCEP-certified PV installer and ISPQ-certified PV instructor. He has experience designing, installing, and servicing both PV and solar thermal systems, and is a curriculum developer and instructor for Solar Energy International.

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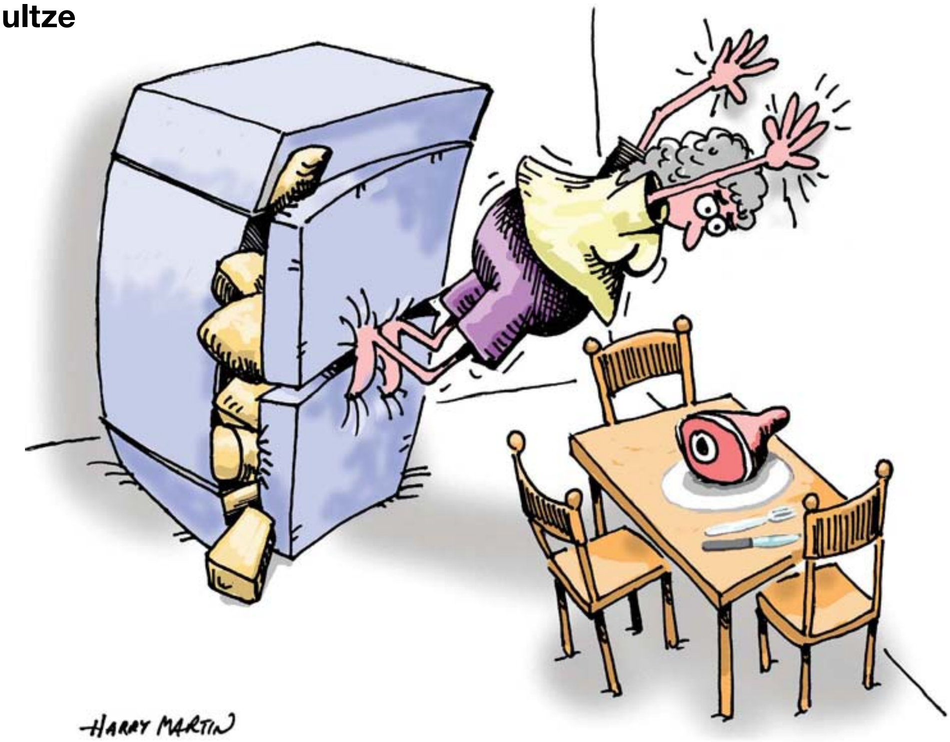
Freezing Pigs

by Kathleen Jarschke-Schultze



I blame the pigs. Well, my husband Bob-O and I don't have pigs...yet. We bought half of a pastured pig from some friends a couple of years ago. It was very tasty pork that had been raised organically. We figured we could raise a pig for ourselves. We have never done that before, but what should that matter?

That's a Wrap

When the time came for us to get the half-pig, I got a call from our friends' butcher. I told her I'd never ordered "cut and wrap" before. She was very cheerful and businesslike. "How thick do you want the pork chops? How many in your family? Two? Then we'll cut the hams in half so they are not too big. Do you want the sausage seasoned with our breakfast herbs or plain?"

She whisked me right through, and soon we were done. About a week later, we met our friends in the parking lot of a small store halfway between our respective homes for the pickup. It was late in the year and a light snow was falling as we handed them the cash and got our boxes of frozen pork out of the trunk.

Cold Deep

It was clear to us now that our SunFrost F10 freezer would not be big enough to accommodate our pork plans. We began looking for a chest freezer that was energy efficient—and big enough to hold our pig half.

After much deliberation, we chose a Frigidaire 15-cubic-foot model with four baskets, a power-on light, and an interior light. We bought it locally and picked it up ourselves. In our neck of the woods, this beats freight delivery, since we have to meet any freight truck two miles from our house, where the paved road ends. If the appliance is damaged or dented, we usually just accept it and take the delivery, as it is such a horrendous pain to send it back or submit a claim at that point. If we pick it up from the store, though, I can inspect it and make sure there is no damage before buying.

The freezer's bright-yellow Energy Guide tag estimated the freezer's yearly operating cost at $38. Yearly consumption was estimated at 357 kWh. This was based on a national average of 10.65 cents per kWh. Of course, since we live off-grid, the electricity cost meant nothing to us, but the kWh figure definitely did.

We brought the freezer into our basement and powered it up. Our basement is pretty cold in the winter and the temperature stays pretty constant. We hooked up an indoor/outdoor thermometer with the indoor reading the basement ambient temperature and routed the outdoor sensor inside the freezer. Then we plugged the freezer into a Kill-A-Watt energy monitor.

Over a period of two and a half weeks, the ambient basement temperature ranged from 49.5°F to 56°F. The freezer temperature ranged from 7.5°F to -13.4°F. The average daily kWh usage was 0.59. The temperature does rise in the basement during the summer, but that is when our solar-electric system also generates the most electricity. In the winter, our microhydro-generated electricity is abundant, so the extra load was easily covered.

I was in and out of the freezer a lot and did put some unfrozen food in there to freeze during that time. We use the chest freezer for long-term storage and the F10 for frozen food we access more often.

Nose to Tail

As with any of our homestead adventures, we like to do a lot of research. First, we bought books and read blogs on raising

pigs. We figured we'd hire a "farm kill" service to fetch the pigs at butcher time and we would just tell them how we wanted them cut and wrapped.

Then my friend Merri, a fabulous food fanatic, told me how she had her own prosciutto hanging and curing in her pantry at home. I was determined to use as much of the pig as I could in as many ways as possible. Lucky for me, there is a "nose-to-tail butchery" movement in the United States. It is a return to the old farm ways where nothing was wasted.

I bought books on butchering, charcuterie, and sausage making. As soon as our friends found out what we were planning, they wanted to get in on it. My sister Mary went a step further. "I'll take half of a pig, and Matthew (my nephew) wants a half. When it's time to butcher, let me know and I'll bring the whole family up for three or four days and we'll help you do it."

No Pasture, No Pork

Bob-O took charge of making a pasture for the pigs. We have a large meadow outside our fenced yard. Since our whole county is open range, shaggy range cattle and herds of horses have frequented the meadow for years. By erecting a fence around a half-acre section now—before we get the pigs—we can see how well our fortifications work against roving herds and wildlife.

Bob-O has plowed the area and we are just waiting for the right weather to use our seed spreader to disperse the mix of grasses, grains, and clover he mixed together. With any luck, the spring rains will help us out and do the early season watering for us. A PV array and pump will convey water up the hill to a 1,500-gallon tank so we can run gravity-fed sprinklers later in the season.

Besides pasture, the pigs will need water. We will be using the bottom of our now-defunct and repurposed water tank (see *HP147*) for a good-sized piggy pool.

This year, we'll establish a good growing pasture. Next year, in May or June, we will buy some feeder pigs and give it a go. That will give us time to raise them to a good weight so they will be ready to butcher come late fall. We're planning on raising just two pigs the first year so we can figure out what we're doing.

Pigs in Heaven

I am adopting the philosophy of Joel Salatin of Polyface Farm who said, "All our animals have a *really good life* and just *one bad day*." I am enthusiastic about raising pastured pigs. I know we will do a good job. It is just another piece of self-sufficiency fitting into our jigsaw puzzle of life. Oh, and don't ask—the pork is already spoken for.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is preparing for pigs at her off-grid home in northernmost California.

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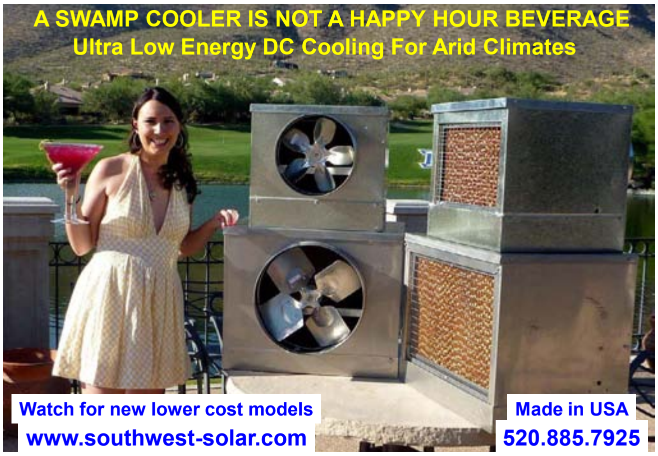

Tight Houses, Efficiency & Indoor Air Quality

A house built to modern standards of tight construction will allow in only a very small amount of outside air, which improves the home's energy efficiency. The flip side of this is that fresh air is needed to dilute the products of human habitation (cooking, cleaning, breathing, combustion, etc.), as well as the chemicals that off-gas from building materials. According to the U.S. Environmental Protection Agency, indoor air pollution levels can be as much as five times higher than outdoor levels. So good ventilation is an important part of maintaining good indoor air quality.

Dilution and at-source (spot) exhausting are the main methods for ensuring good indoor air quality. Although houses can be designed to "self-ventilate," this process depends upon local climate conditions and wind shading—protection by tall walls and trees—which are not controllable. Why not just open the windows? In some very mild climates, this might be a fine strategy. But in most of the United States, trying to ensure adequate air exchange defeats the energy-saving intent of a well-sealed building envelope.

Blower-door tests can reveal how "leaky" or "tight" a house is by measuring how difficult it is to pull air out of the house when it's all closed up. The rater closes the windows, doors, fireplace dampers, and other openings that are normally closed when the HVAC system is running. The blower door is aluminum-framed canvas with a large fan. When placed in a central outside doorway, it can either pressurize or depressurize the house. As the fan pulls air out of the house, the inside air pressure drops below the outside air pressure. To quantify the process, the rater adjusts the fan until the pressure difference between inside and outside is 50 Pascals. A pressure gauge, connected separately to both outdoor and indoor air with small rubber hoses, determines the pressure difference, and with a conversion table, the rater can determine airflow.

The fan's airflow, the climate, the size of the house, and the exposure to wind is used to calculate the normal air changes per hour (ACH) rating for the house. With the blower door test at a negative 50 Pascals, a typical home might leak at 15 air changes per hour (15 ACH50). Tightly constructed houses may measure 1 ACH50 or less. (The infiltration rate of a "passive house" has to be 0.7 ACH50 or less.) Estimating the natural infiltration rate of a building is an important step in evaluating indoor air quality and the possible need for mechanical ventilation.

Courtesy Allison A. Bailes III

A blower door test can tell you how leaky—or tight—your home is.

Both heat and energy recovery ventilators use fans to bring in outside air and to exhaust air, balancing the amount of air in versus out. This air balance minimizes airflow through the building envelope—by reducing the pressure differential between inside and outside. They recover energy from the outgoing airstream via a heat exchanger, which allows heat to move between the two airstreams without mixing or cross-contaminating them.

There are various recommendations for sizing mechanical ventilation systems. An older one called for 0.35 air changes per hour (ACH). Alternate recommendations are based upon a recommended airflow per room. Figures vary by manufacturer, but the American Society of Heating, Refrigeration and Air Conditioning Engineers—which sets standards for good residential indoor air quality—recommends continuous ventilation of 0.01 cfm per square foot of living space, plus 7.5 cfm per person. So a 1,500-square-foot home with four residents would require 45 cfm.

—Adapted from "Heat & Energy Recovery Ventilators" by Neil Smith (*HP145*) and "How Efficient is Your House?" by Allison A. Bailes III (*HP106*)